Study of Transportation Accident Severity

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1. Introduction

When and if a high-level waste repository begins to operate in the United States, a large backlog of irradiated fuel from the nation's power reactors will begin to move on highways and rails. The situation would be radically different from the present or past when few shipments occurred. For the most part, irradiated fuel is currently stored at nuclear power reactors where it is generated.

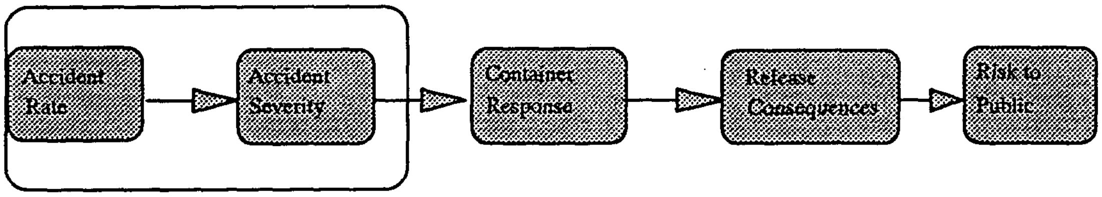
With 3000 tons of irradiated fuel or more scheduled to move each year , and shipments criss-crossing the country, from the east to Nevada, transportation accidents will inevitably occur for the myriad of reasons that can cause any accident involving goods of commerce: driver error (fatigue, drugs, excessive speed and so on), equipment malfunction (faulty brakes, bridge collapse, so on) and acts of nature. Careful safety planning can reduce the probabilities and mitigate the effects of an accident, but nuclear shipments have otherwise no divine protection. From accident data, one can estimate the likely number of accidents, including the number which will be minor and major.

The question this report addresses is -- how likely is it that a severe accident could actually broach a shipping cask and lead to a release of radioactive material? Could such an accident happen once a year or once every million years? This report investigates in detail the accident rate and the accident severity spectrum, evaluating 40 severe accidents in some detail.

To fully determine the risk of transporting irradiated fuel, one would need to know, given an accident, the container response, the expected release and dispersion of radioactive pollutants, the pathways of radiation to humans in rural, suburban and urban settings, the expected number of cancers and genetic effects and the economic costs.

These related questions, how much radioactive material could be released to the environment and the resultant health and economic impacts, that is, the risk in terms of cancers and genetic effects per year, are not dealt with in this report. The diagram below illustrates the issues we are addressing.

Simplified Risk Assessment Diagram



Discussed in this Study

Since 1974, transportation of nuclear materials has been a contentious issue in the United States. The debate began with the New York Attorney General seeking to enjoin the transportation of plutonium by aircraft. Plutonium in liquid form, separated at the now closed West Valley reprocessing plant in upstate New York, was being flown out of New York City's Kennedy Airport to Europe in casks designed to withstand only a 30 foot drop. The court suit and the public attention it generated led to Congressional action by U.S. Representative J Scheuer, in the form of an amendment to the 1975 Nuclear Regulatory Commission authorization bill that prohibited air transport of plutonium until a container that could withstand an air crash was designed and tested. In 1976, the City of New York further prohibited the transport of irradiated fuel from Brookhaven National Laboratory on Long Island through the City. Soon thereafter, hundreds of local communities were passing transportation ordinances similar to that of New York City.

Following passage of the Scheuer amendment, the Nuclear Regulatory Commission initiated a rule-making on the air transport of radioactive materials, preparing an EIS on the subject.[1] Accident rates, accident severities (I through VIII) and container response were estimated using an accident severity scheme developed by Sandia.[2] Since little information was available on container response in an accident and estimated releases of radioactive material, crude and conservative assumptions were proposed in NUREG-170. Essentially all volatiles and a small percentage of particulates were assumed to be released if the accident exceeded regulatory requirements for a Type B container. A computer program, RADTRAN, summed up estimated releases of radioactive materials under varying accident conditions to obtain the risk of transporting radioactive material. In the ensuing years, the computer code was refined, primarily to better account for risk due to normal (non-accident) transport, such as the dose to

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[1] NRC, Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes, NUREG-0170, December 1977.

[2] Sandia blue report

transportation workers, pedestrians and persons sharing the transportation right of way, and also to account for neutron dose.

With RADTRAN, the estimated probability of releasing a specific amount of radioactive material in a specific demographic setting must also be specified. The model requires that the accident severity matrix and within each severity category, the amount of radioactive material released, be specified. The accident severity categorization scheme itself could be any number of categories, six, eight or twenty. The prime issue is assigning probabilities and radioactive releases for each accident severity.

While the 1977 accident severity scheme was intuitively clear, the assignment of probabilities for each accident severity and estimates of radioactive releases were quite crude. In some cases, real accident data was not available and was constructed from theoretical models. Little accident data was available for severe accidents. But the major uncertainty involved container response to an accident. Since shipping containers are not tested to destruction and since no major accidents have led to releases of radioactive material, there was absolutely no data with which to estimate radioactive releases for each accident severity class other than "engineering judgment."

An attempt was made to remedy this weakest component of the 1977 risk formulation in 1981. Rather than simply assume that specific amounts of radioactive material would be released in each accident severity category, Wilmot[3] developed a fault-tree model. Based on sketchy experimental data, the response of cask components and irradiated fuel to specific accident environments was projected and aggregated to determine the release of radioactive materials under specific accident scenarios. The accident severity classification scheme was changed from eight to six categories. The strength of this approach is that it directly applied to real cask components: bolts, welds, seals, relief valves and so on. But the main weakness of this fault-tree approach was the assignment of accident probabilities to the accident environments that could lead to a release of radioactive materials.

In 1991, the Nuclear Regulatory Commission attempted a new approach to estimating probabilities of radioactive releases under different accident environments. This approach, using temperature and strain as key container response parameters[4], had the virtue of better relating container response under real accident conditions. The accident severity scheme was broken into 20 categories and the RADTRAN model[5] was slightly altered to accommodate the scheme. Using a study of real accident data by Eggers[6], Fischer concluded that no accident that has ever occurred in the United States would have led to a release of radioactive materials. A major weakness of the Fischer study was incomplete attention to the weakest components of the cask: welds, valves, bolts and seals. Another major weakness was the use of lead melting point as a critical

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[3] Wilmot, EL, 1981.
[4] Fischer, LE et al, 1991
[5] RADTRAN IV
[6] Eggers, P,

temperature since several cask components (seals, neutron absorbers) degrade at much lower temperatures.

Major, extremely destructive transportation accidents have occurred in the United States. These range from bridge drops, where cars and trucks have plunged 80 feet onto rocks, to truck fires which have burned up to 2 hours, 40 minutes, at temperatures exceeding 1900 °F and train fires which have burned for eight days. The 1988 San Francisco (Loma Prieta) earthquake flattened one roadway on top of another; the crush forces were massive. In short, accident environments have apparently greatly exceeded the Nuclear Regulatory Commission's hypothetical accident conditions[7], a drop of 30 feet onto an immovable pad or 40 inches onto a spike, or an engulfing 1/2 hour fire at 1475 °F. But these real accidents must be investigated in detail to make a valid comparison with Nuclear Regulatory Commission regulations. A review of these real extremely severe accidents is a major component of this report.

The history of estimating the probability and consequences of nuclear transportation accidents, sketched out briefly above, is presented in Chapter 2. In Chapter 3, we review 35 real accidents that have occurred in the United States to determine evaluate the real forces, impact, puncture and thermal, which can occur. In Chapter 4, we place these accidents into the accident severity scheme, to evaluate whether these accidents exceeded the hypothetical accidents requirements spelled out by Nuclear Regulatory Commission regulations. In Chapter 5, we present our summary and conclusions. The Appendix contains a summary description of the accidents we investigated.

2. History of Probability/Consequence Estimates

2.1 NUREG-170

The percentage of radioactive inventory released in an accident depends on the accident severity and the response of the container. Severe accidents would be expected to release a larger percentage of the package inventory; minor accidents might not breach the package at all. Thus, accidents and container response must be classified according to accident severity and the relative occurrence of accidents of each severity in each transport zone must be estimated. The risk is then the sum over all accident severities of the product of each accident probability times the consequences of the accident of that severity. While the overall accident rate is fairly well known, the probability of each accident severity is less well known, particularly for extremely severe accidents.

Consider first the accident severity classification scheme for aircraft devised in NUREG-170. The classification scheme is related to the hypothetical accident testing requirements for shipping packages and is shown in Figure 1. The two axes are impact and fire duration. Impact is broken into eight divisions. The first two divisions

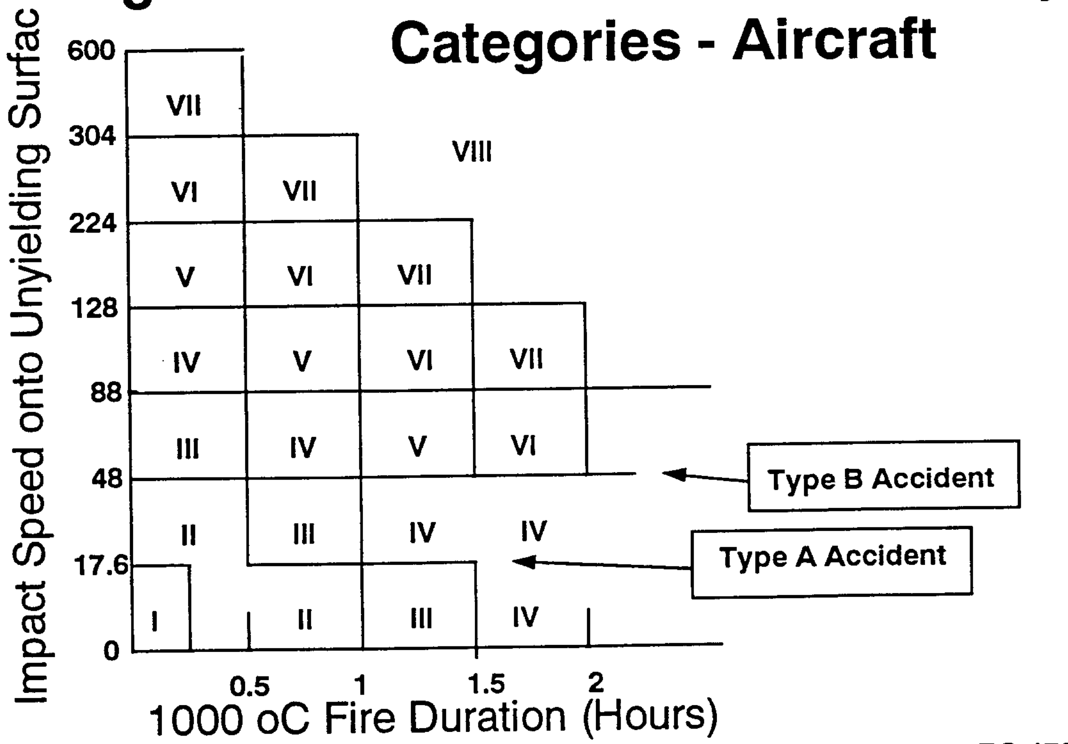
[7] 10 CFR Part 71...

correspond to the regulatory standards for type A and type B packages. Category I corresponds to a drop of 4 feet or less, a drop which a type A package is designed to withstand. The second division corresponds to a drop of 30 feet or less, which a type B package must withstand. The remaining divisions are somewhat arbitrary, chosen such that 60% of impacts are severity category III or less, 70% of accidents are severity category IV or less, 80% of accidents are severity category V or less, 85% of accidents are severity category VI or less and 95% of accidents are severity category VII or less. Fire duration divisions were chosen so that the accident severity increased one category for each additional 1/2 hour of a 1000 ^{o}C fire. This equivalence between a fire duration and impact speed had no quantitative basis. For example, Fig. 1 shows that a Category III accident could either be a 48 kph impact without a fire or a one hour fire with no impact, but no reports by Sandia or the Nuclear Regulatory Commission demonstrated technically or experimentally that these two different accidents caused equivalent damage or led to identical radioactive releases.

The overall accident rate for aircraft, 1.44×10^{-8} accidents per kilometer, is broken into accidents of each severity category, as shown in Table 1. Since accidents do not involve impact onto an unyielding surface, but rather accidents onto real surfaces which yield somewhat, depending on the surface, the fractional occurrences are "derated" to account for real surfaces. The country as a whole is divided into generic surface types: water, sand, clay, tuff, granite and abutments and steel. The net result of this "derating" scheme is that most of the higher severity accidents are moved into lower severity categories. As can be seen from Table 1, while 3% of all aircraft accidents are in the most severe category, Category VIII, when the actual surfaces are taken into account, the percentage in Category VIII becomes 0.03%.

The fractional occurrences are further broken down into whether they occur in urban, suburban or rural areas. For aircraft, the assumption is that the most severe accidents, Categories VII and VIII, occur in flight over rural areas, while those intermediate in severity, Categories III - VI, occur in takeoffs and landings at airports which are generally located in suburban areas.

Fig. 1 NUREG-170 Accident Severity Categories - Aircraft



Source: NUREG-170

Figure 1. Fractional Occurrences For Aircraft Accidents By Accident Severity Category And Population Density Zone

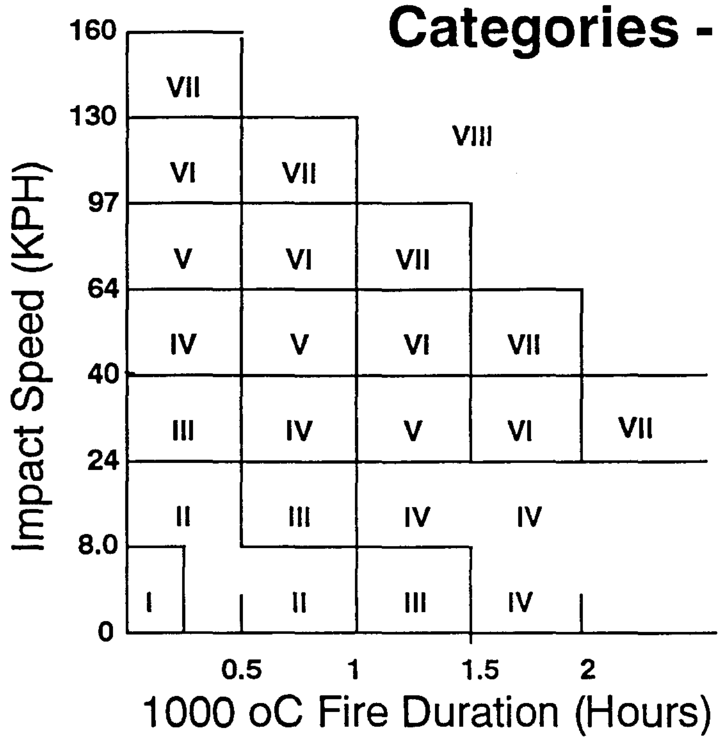
Accident Severity Category	Fractional Occurrences Unyielding Surface	Real Surface	Fractional Occurences By Population Density Zones Low	Medium	High
I	.57	.447	.05	.9	.05
II	.16	.447	.05	.9	.05
III	.09	.0434	.1	.8	.1
IV	.05	.0107	.1	.8	.1
V	.03	.0279	.3	.6	.1
VI	.03	.0194	.3	.6	.1
VII	.04	.0046	.98	.01	.01
VIII	.03	.0003	.98	.01	.01
TOTAL	1.00	1.00			

*Overall Accident Rate= 1.44 X 10^{-8} accidents/kilometer for commercial aircraft.

Source: Table 5-2, NUREG-0170

The same method for classifying truck and train accidents is carried out in NUREG-170. The accident severity scheme for trains is shown in Figure 2. Because of the much greater masses involved, the velocity scale for trains is much lower, that is, trains at comparable speeds can cause considerably more damage to a cask than aircraft.

Fig. 2 NUREG-170 Accident Severity Categories - Trains



Source: NUREG-170

The fractional occurrences for different severity categories are determined by examining the causes of collisions, in order to determine the actual car speed at impact[8]. The fractional occurrences are for cargo-carrying cars of the train, not for the locomotive. The overall accident rate is 0.93 x 10^{-6} railcar accidents/railcar-kilometer, assuming an average train length of 70 cars and 10 cars involved in an accident. From real accident data and a host of assumptions about how cars are slowed in different accidents, Sandia calculated the probabilities of differing impact speeds. To obtain severity frequencies, Dennis examined 700 accidents, using a derating scheme first employed in Clarke etal to determine the actual impacts, not pre-accident speeds, in transportation accidents. From this he plotted a curve of cumulative probabilities, the probabilities that a fixed percentage of accidents would be less than X mph. Almost all the accidents considered were at the lower speed range which were then extrapolated to

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[8] Larson et al

the upper range where little or no data exist. The uncertainties of this approach are therefore high at the upper range. We discuss this in more detail in Chapter 3. The fractional occurrences for trucks and trains are shown in Tables 2 and 3, respectively. Note that for trains, only 6 cars out of 100,000 cars involved in rail accidents are in Category VII, and 1 out of 100,000 railcars in accidents are in Category VIII accidents. As we discuss later, on the basis of our review of rail accident statistics, we are of the opinion these expected occurrences are too low. The fractional occurrences are further broken down according to population zones. The most severe accidents are assumed to occur in rural areas and the least severe in high population zones. There is no basis for this correlation for fire or impacts. High speed train impacts generally occur at downgrades, particularly if curves are present. Downgrades are as likely in rural as suburban areas. Many long duration fires have occurred in suburban areas, particularly on lines carrying combustible materials. Again these fires often occur near downgrades and curves which are not necessarily located in rural areas. Table 2 shows the accident severity distribution for trains. Incorrectly identifying the demographic locations of long duration fires lowers the risk estimates by a factor of 10.

Table 2. Fractional Occurrences For Truck Accidents By Accident Severity Category And Population Density Zone

Accident Severity Category	Fractional Occurrences	Fractional Occurrences By Population Density Zones Low	Medium	High
I	.55	.1	.1	.8
II	.36	.1	.1	.8
III	.07	.3	.4	.3
IV	.016	.3	.4	.3
V	.0028	.5	.3	.2
VI	.0011	.7	.2	.1
VII	8.5×10^{-5}	.8	.1	.1
VIII	1.5×10^{-5}	.9	.05	.05

*Overall Accident Rate = 1.06×10^{-6} accident/kilometer

Source: Table 5-3, NUREG-0170

Table 3. Fractional Occurrences For Train Accidents By Accident Severity Category And Population Density Zone

Accident Severity Category	Fractional Occurrences	Fractional Occurrences By Population Density Zones Low	Medium	High
I	.50	.1	.1	.8
II	.30	.1	.1	.8
III	.18	.3	.4	.3
IV	.018	.3	.4	.3
V	.0018	.5	.3	.2
VI	1.3×10^{-4}	.7	.2	.1
VII	6.0×10^{-5}	.8	.1	.1
VIII	1.0×10^{-5}	.9	.05	.05

*Overall Accident Rate = 0.93×10^{-6} railcar accident/railcar-kilometer.

Source: Table 5-5, NUREG-0170

Corresponding to each accident severity, the Nuclear Regulatory Commission proposed two models for the fraction of radioactive material released, as shown in Table 4. In Model I, no material was released in Categories I and II, and 100% for Categories III through VIII. In Model II, 1% of radioactive material is released in Category III, 10% in Category IV and 100% in Categories V through VIII. These percentages are for **available** gaseous and volatile materials. The definition of "available" further delimits the percentage of radioactive inventory that is actually projected to be released.

Table 4. Release Fractions from Spent Fuel Cask

Severity Category	Release Fractions Model I	Model II
I	0	0
II	0	0
III	1	0.01
IV	1	0.1
V	1	1
VI	1	1
VII	1	1
VIII	1	1

Source: NUREG-0170

The accident severity frequencies, population zone frequencies and release fraction distributions employed in the 1977 RADTRAN risk analysis were highly uncertain for several reasons:

- the expected release fractions, Table 4 above, had little technical basis. The percentages released were simply correlated to the hypothetical accident conditions for Type B containers. No physical model related the mechanical or thermal forces on a cask to the amount released.
- the correlation between thermal conditions and accident severities was never established. The accident severity categories and fractional occurrences were based on impact. Why would an increase of one half-hour in fire duration mean the accident severity should increase one category? And why does a half hour fire increase equate to an increase of 16 kph in velocity, for example? Again, the original Sandia formulation and NUREG-170 had no physical model which underlay the

accident severity scheme.

- the accident data base was thin. Very few severe accidents were analyzed. Most of the probabilities were calculated with a Monte Carlo model using assumed physical models. With time, these physical parameters, especially for fire temperature and duration, have changed. For example, the maximum amount of combustible material that can be transported has increased with double trailers. The physical model also did not incorporate all possibilities. As one example, in estimating fire duration probabilities, Sandia did not anticipate the fact that pipelines transporting gasoline are co-exist along the same right-of-way as rail tracks and that a train accident could be correlated with a pipeline explosion, such as occurred in 1989 in San Bernardino, California. As another example, Sandia assumed that in an accident involving a gasoline tanker would be spread over 200 square feet and burn at a constant rate. But in the Caldecott Tunnel fire in Oakland, California in April, 1983, gasoline remained in one location and was fed by air like a blowtorch. This caused a highly localized, all-engulfing, high temperature fire for over 2 hours. The probability of such a severe fire, according to Sandia researchers, was essentially infinitesimal.
- the correlation between fractional occurrences and population density zones, particularly for long duration fires, had no technical basis and is probably wrong. Long duration fires have quite often occurred in suburban zones.

2. Sandia 1981

In 1981, Sandia researchers attempted to resolve the weakest feature of the above accident analysis, the lack of a physical model to estimate the release of radioactive materials in a severe accident. A fault-tree model was developed to estimate releases from spent fuel into the cask and from the cask into the outer environment. Sandia researchers estimated the failure of cask components under specific accident conditions. The different accident severity categories were divided into six classes. Categories I and II, which do not lead to a release of radioactive materials in the fault-tree approach, were equivalent to the first two categories in NUREG-0170. Category 3 corresponded to an impact greater than the regulatory drop test, severe enough to damage the cask seals and to spall crud from the exterior of spent fuel. Category 4 corresponded to an impact sufficient to damage the cask seals and create cracks or splits in spent fuel cladding. Under a Category 4 accident, gases and volatiles would enter the cask cavity. A Category 5 accident would involve forces severe enough to damage the cask seals and be accompanied by a fire severe enough to cause burst rupture of the fuel rods. A Category 6 accident would involve fuel oxidation, in which fuel oxidized from UO_2 to U_3O_8. This oxidation would cause fuel expansion and particulates would also be released from the cask.

While the physical model was improved with this fault-tree analysis, the probability estimates for these severe accidents were still based on the probability estimates made earlier in 1977 by Dennis and others. A mere three pages are devoted to determining the accident rates and probabilities. The analysis assumes that fire and impact are independent variables. The probabilities of severe accidents in each most severe category are then multiplied to determine that a Category 6 accident would occur once in a million years. This is a major error since 1% of truck fires and 1.6% of train fires are correlated with an impact (fires may also occur without impact). Therefore, it is not true that the impact and fire parameters are independent. Thus, while the physical model was improved with the 1981 Sandia analysis, the probability estimates were simply wrong. In addition, the estimates did not take into account that human error could alter these probability estimates. The model did not take into account, for example, that cask bolts could be incorrectly tightened, too loose or too tight, and that a greater percentage of radioactive inventory could be released to the environment with a higher probability.

3. Modal Studies

The correlation between accident severity probabilities and cask damage was tightened with later analysis by Fischer. As discussed above, the relationship between the thermal environment, mechanical forces and the accident severity scheme developed in NUREG-0170 was somewhat arbitrary and not well formulated. The fault-tree method developed by Wilmot, based on the failure of cask components and fuel, improved the correlation between the accident environment and releases of radioactive materials from the cask. But the probability of such events, that is, the relationship between radioactive releases and the highway and rail environment remained murky. Fischer attempted to tie together the accident environment with radioactive releases. Rather than the thermal and mechanical forces on a cask, he chose as parameters the response of the cask to these forces.

The Modal Study employed two parameters to describe the cask response to the mechanical and thermal forces on a cask in an accident: strain and temperature. For the thermal response parameter, Fischer chose the temperature at the middle of the lead shield thickness. For the cask response to mechanical forces on a cask, he chose the parameter, strain or elongation of the inner metal shell. Fischer then proceeded to examine real severe forces which have occurred on the highway and rail, employing data previously developed by Eggers[9], to determine the response of a cask to these extreme forces.

Rather than the somewhat arbitrary 1/2 hour temperature divisions, Fischer chose the following temperature divisions in the accident severity scheme:

> T1 = 500 ^{o}F, a temperature below the melting point of lead, 621 ^{o}F. This is a region of constant phase for lead.
> T2 = 600 ^{o}F, also a region of constant phase, but near the lead melting point
> T3 = 650 ^{o}F, above the melting point of lead, where the lead volume has expanded 10% and the seals are expected to leak and
> T4 = 1050 ^{o}F.

It is important to recognize that a large heat input is needed to melt lead, to raise the lead

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[9] Eggers, PE

temperature from T2 (600 ^{o}F) to T3 (650 ^{o}F). Newer generation casks, however, will probably not contain lead since they will be designed to hold more fuel, after aging 5 to 10 years. Lead is employed as a gamma attenuator. But since lead will push the weight of the cask above standard highway weight limits (40 tons) into the overweight region that necessitates State overweight permits, cask manufacturers will probably use depleted uranium. The above temperature categorization scheme will then not be as useful for the newer generation casks.

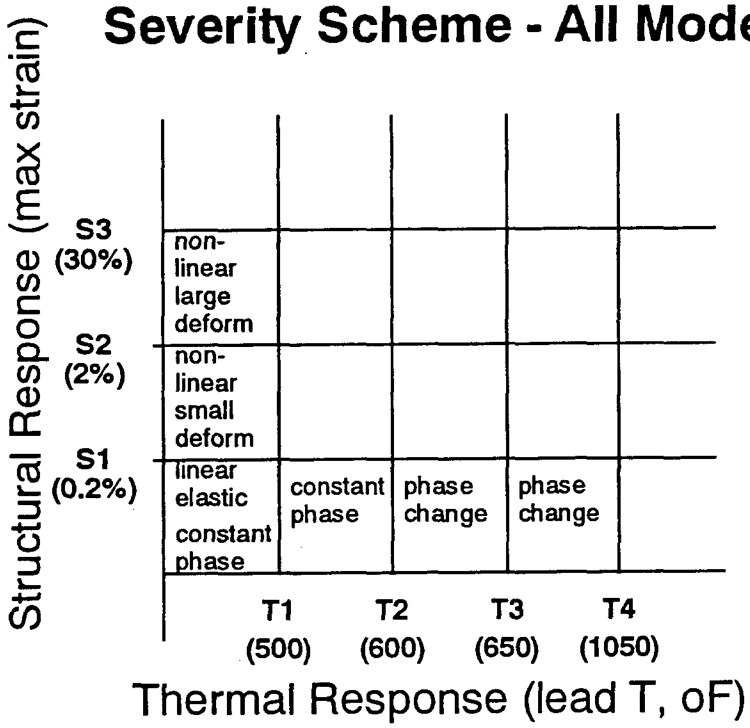
Further, as we discuss later, Fischer chose an external water jacket neutron absorber for his standard model cask. This choice is also not appropriate for newer generation casks which use borated plastic neutron absorbers. The water jacket, assumed to be dry in severe fires or impacts, serves as an air space thermal insulator. Without this thermal insulator and lead, the cask would be expected to heat up more rapidly in a high temperature, long duration fire.

For the cask response to impact forces, Fischer chose the parameter strain at the inner shell of the cask structure and the following strain divisions in the accident severity scheme:

S1 = 0.2% strain at the inner shell. This corresponds to less than a 40g axial force and an elastic cask response. At these forces, within the type A container regulatory limits, there is no lead slump.
S2 = 2% plastic strain at the inner shell. At these forces, within the type B container regulatory limits, there is some lead slump and up to 10% of the fuel rods leak.
S3 = 30% strain at the inner shell. This is below the fracture strain of 304 stainless steel. At these forces, cracking at cask welds and seal leakage is expected.

Employing these parameters, the Modal Study accident severity scheme is shown in Figure 3.

Fig. 3 Modal Study Accident Severity Scheme - All Modes



3. Severe Highway and Rail Accidents

Detailed discussion of severe highway and rail accidents, based on Appendix descriptions. Placement of severe real accidents into Fischer and Sandia accident severity categories. Examples:

- Loma Prieta 1988 earthquake caused upper roadway to fall on lower roadway. Crush forces amounted to 740,000 tons, but maximum crush force considered by Fischer/Eggers is 100 tons (railroad), 30 tons (highway).
- Helena, Montana and several other train accident/fire involved 90 ton tanker cars flying over 1/4 mile. Will estimate impact forces.
- San Bernardino, California train wreck, subsequent pipeline explosion involved train speeds up to 90 mph.
- Roseville, California 1973 explosion of 18 boxcars, each containing 44 tons of 250-lb bombs. A circular area 1 1/4 miles in radius was totally leveled.

4. Probability Estimates

Sandia, Wilmot and Fischer estimate probabilities of severe accidents. Several of the accidents considered were expected to occur once in a million years, yet they have occurred within the past 20 years. The Sandia, Wilmot and Fischer probability methods are therefore flawed. This will be discussed in some detail.

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NTSB74a *Hoppy's Oil Service, Inc, Truck Overturn and Fire, State Rte 128, Braintree, Massachusetts, October 18, 1973*, National Transportation Safety Board, NTSB-HAR-74-4, 1974.

NTSB76b *Derailment of Tank Cars with Subsequent Fire and Explosion on Chicago, Rock Island and Pacific Railroad Company Near Des Moines, Iowa, September 1, 1975,* National Transportation Safety Board, NTSB-RAR-76-8, 1976.

NTSB78 *St Louis Southwestern Railway Company Freight Train Derailment and Rupture of Vinyl Chloride Tank Car, Lewisville, Arkansas, March 29, 1978,* National Transportation Safety Board, NTSB-RAR-78-8, 1978.

NTSB79a *Derailment of Louisville & Nashville Railroad Company's Train No. 584 and Subsequent Rupture of Tank Car Containing Liquified Petroleum Gas, Waverly, Tennessee, February 22, 1978,* National Transportation Safety Board, NTSB-RAR-79-1, 1979.

NTSB79b *Louisville & Nashville Railroad Company, Freight Train Derailment and Puncture of Hazardous Materials Tank Cars, Crestview, Florida, April 8, 1979,* National Transportation Safety Board, NTSB-RAR-79-11, 1979

NTSB 81 *Illinois Central Gulf Railroad Company Freight Train Derailment, Hazardous Material Release and Evacuation, Muldraugh, Kentucky, July 26, 1980,* National Transportation Safety Board, NTSB-RAR-81-1, 1981.

NTSB83a *Derailment of Illinois Central Gulf Railroad Freight Train Extra 9629 East (GS-2-28) and Release of Hazardous Materials at Livingston, Louisiana, September 28, 1982,* National Transportation Safety Board, NTSB/RAR-83/05, 1983.

NTSB83c *Multiple Vehicle Collisions and Fire, Caldecott Tunnel Near Oakland, California, April 7, 1982,* National Transportation Safety Board, NTSB/HAR-83/01, 1983.

NTSB85b *Vinyl Chloride Monomer Release from a Railroad Tank Car and Fire, Formosa Plastics Corporation Plant, Baton Rouge, Louisiana, July 30, 1983,* National Transportation Safety Board, NTSB/RAR-85/08, 1985.

NTSB85c *Denver and Rio Grande Western Railroad Company Train Yard Accident Involving Punctured Tank Car, Nitric Acid and Vapor Cloud and Evacuation, Denver, Colorado, April 3, 1983,* National Transportation Safety Board, NTSB/RAR-85/10, 1985.

NTSB86b *Derailment of St Louis Southwestern Railway Company (Cotton Belt) Freight Train Extra 4835 North and Release of Hazardous Materials Near Pine Bluff, Arkansas, June 9, 1985,* National Transportation Safety Board, NTSB/RAR-86/04, 1986.

NTSB89 *Collision and Derailment of Montana Rail Link Freight Train with Locomotive Units and Hazardous Materials Release, Helena, Montana, February 2, 1989,* National Transportation Safety Board, NTSB/RAR-89/05, 1989.

NTSB90b *Derailment of Southern Pacific Transportation Company Freight Train on May 12, 1989 and Subsequent Rupture of Calnev Petroleum Pipeline on May 25, 1989*, San Bernardino, California, National Transportation Safety Board, NTSB/RAR-90/02, 1990.

NTSB91 *Derailment of CSX Transportation Inc Freight Train and Hazardous Materials Release Near Freeland, Michigan on July 22, 1989*, National Transportation Safety Board, NTSB/RAR-91/04, 1991.

Impact

CHP89 *1989 Loma Prieta Earthquake*, Summary Report, Department of California Highway Patrol, Sacramento, California, 1989.

Mountaineer85 Newclips, I-40 Rockslide, March 5, 1985, The Mountaineer, Waynesville, N.C., 1985.

NTSB67 *Collapse of US 35 Highway Bridge, Point Pleasant, West Virginia, December 15, 1967*, National Transportation Safety Board, NTSB-SS-H-2, 1967.

NTSB74b *Greyhound Bus Collision with Concrete Overpass Support Column on I-880, San Juan Overpass, Sacramento, California, November 3, 1973*, National Transportation Safety Board, NTSB-HAR-74-5, 1974.

NTSB74c *Automobile Crash Off the Silliman Evans Brdige, I-24/65, Nashville, Tennessee, July 27, 1973*, National Transportation Safety Board, NTSB-HAR-74-2, 1974.

NTSB 76c *Head-On Collision of Two Penn Central Transportation Company Freight Trains Near Pettisville, Ohio, February 4, 1976*, National Transportation Safety Board, NTSB-RAR-76-10, 1976.

NTSB76d *Collision of Reading Company Commuter Train and Tractor-Semitrailer Near Yardley, Pennsylvania, June 5, 1976*, National Transportation Safety Board, NTSB-RAR-76-4, 1976.

NTSB84 *Collapse of a Suspended Span of Interstate Route 95 Highway Bridge Over the Mianus River, Greenwich, Connecticut, June 28, 1983*, National Transportation Safety Board, NTSB/HAR-84/03, 1984.

NTSB85a *Collision of Isle of Wight County, Virginia Schoolbus with Chesapeake and Ohio Railway Company Freight Train, State Route 615 Near Carrsville, Virginia, April 12, 1984*, National Transportation Safety Board, NTSB/HAR-85/02, 1985.

NTSB86a *Collapse of the US 43 Chickasawbogue Bridge Spans Near Mobile, Alabama, April 24, 1985,* National Transportation Safety Board, NTSB/RAR-86/01, 1986.

NTSB88 *Collapse of New York Thruway (I-90) Bridge Over the Schoharie Creek near Amsterdam, New York, April 5, 1987,* National Transportation Safety Board, NTSB/HAR-88/02, 1988.

NTSB90a *Collapse of the Northbound US Rte 51 Bridge Spans over the Hatchie River near Covington, Tennessee, April 1, 1989,* National Transportation Safety Board, NTSB/HAR-90/01, 1990.

Notes

Notes on NTSB Documents

LN79 shows even slow speeds are not accident prevention, 30 mph. Part of train descending and part ascending around curve caused pinch and lateral push over outside track. Problem was long train and heavy load. Then pool at bottom of embankment caused burn over 60 hour period. This alters assumptions and probability of accident involving long duration fire for rail accidents.

No temperature analysis, but based on chemicals should be able to approximate temperature.

Accident did not involve major errors in judgment or faulty equipment. Emergency response lacking, though use of Air Force plane was helpful. Problems with command center.

ICG80 also involved slow speeds, about 36 mph, but indicates problems with class 3 track maintenance. Here Ft Knox personnel assisted in emergency response.

SP82 indicates waybill problems with consolidating radioactive or hazardous material into trailers loaded onto flat cars. Conductors and dispatchers generally do not know the extent and hazard of shipments to respond effectively in an emergency. An accident at Ludowici, Georgia on March 23, 1982 and at LaPorte Indiana on April 2, 1982 were under similar circumstances. At Ludowici, Georgia, a class B poison, was released into the atmosphere during the post derailment fire. The trailer was not placarded and the train consist did not indicate the presence of hazardous materials. An intense fire burned for 50 hours. Information on the poison received about 31 hours after the derailment. At LaPorte, Indiana, an oxidizing material, which when wet becomes chlorine gas, was released. The container was not placarded, but chlorine-like odor was detected. About 200 people were evacuated.

ICG82 33 derailed tank cars which were loaded actually separated from their trucks In 7 cases, all or part of the lading was released as part of damage to the outlet valve.

NV85 collision with train at 44 mph. The passenger compartment was ripped off the chassis. Took about 69 seconds for the train to stop after emergency brake applied. This train was mainly empty, weighing 5,232 tons. Some of the other train accidents involved trains weighing twice as much.

FPC83

DRGW83 failed coupler

Thru87 height of bridge above Schoharie Creek is 80 feet. Underlying are cobbles and boulders that may be several feet in diameter and weigh 300 to 600 pounds. Should consider fall of truck and attached trailer onto boulder as accident possibility. Additional weight of trailer may be important. Puncture or impact forces could be large. What is weight of falling bridge span? What are impact forces?

SLSR85 butyl acrylate (flame temperature?) and ethylene oxide, flammable liquid. This accident shows that when hazardous chemicals are involved, a decision is made to evacuate rather than fight the fire, allowing fire from punctured cars to caused unpunctured cars to explode and burn, contributing to the overall fire. This argues for special trains rather than mixed goods trains.

MRL89 cars containing hydrogen peroxide, isopropyl alcohol and acetone involved. A mixture of hydrogen peroxide and molten polyethyelene could explode. Estimated force of second explosion equivalent to 10 tons of TNT (interaction between 9.1 tons of 70% hydrogen peroxide and 0.9 tons of polyethylene.

NTSB89 bridge span 45 feet high collapsed.

NTSB74 difficult to know the explosive force. Will have to make estimates based on extent of area parts were thrown, that is, the kinetic energy of pieces. But broken glass was reported 3.5 mi east and 2.5 mi north which gives some indication of explosive force The threshhold required for glass breakage is 0.25 psi. Could we then calculate $1/r^2$ law to get overpressure at 10 feet?

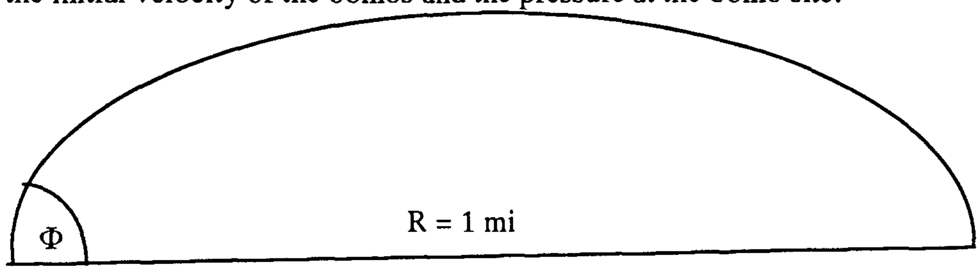
NTSB85 Blast overpressure 0.3 psi for a fully loaded tractor-trailer at 4000 feet from the blast. Could we then calculate $1/r^2$ law to get overpressure at 10 feet? Does this put much stress on a cask? What is the probability of being hit by shrapnel at 10 feet, if the probability at 4000 feet is 1 in a million? Does this go as $1/r^2$? From size of crater may be able to have another check on explosive force (crater 27 feet deep and 35 feet wide).

From Army detonation manual, a crater 27' deep, with no tamping, implies 1470 kg TNT, using the formula,

$$K = R^3MC$$

where R is 9 meters, M=1.12 for earth, and C=1.8 for no tamping. K is in units of kg TNT.

NTSB75 Bombs were blown as far as 1 mile from the main crater area. Windows were shattered in a home 5 miles from the accident. From these two facts, one can determine the initial velocity of the bombs and the pressure at the bomb site.



$$R=\frac{2v_o^2\cos\Phi\sin\Phi}{g}$$

If $\Phi = 45^{o}$, $v_o = 411$ ft/sec or 280 mph. But the above does not include frictional forces, so the initial speed was much greater.

Just like some highway segments, some RR segments have higher accident rates. Because of the grades, this section had many fires due to overheated brakes. The history of this division of the Southern Pacific RR indicates 237 car fires during a five-year period including 14 fires from overheated journals, 184 fires from brakeshoe sparks, 2 fires from friction, 5 from spontaneous combustion, 10 in fans of refrigeration units and 22 from other causes.

NTSB90 Is it standard to have pipelines next to railroad tracks? Does this increase the fire hazard probability? In this case, pipeline was 14 inch and 6 1/2 mi to terminal and filled with gasoline. This corresponds to 2400 barrels an hour. About 9,400 barrels (55 gallons a barrel?) spilled. [This is much more than Sandia's estimates for a duration/heat fire.]

Note: A similar accident occurred June 27, 1989 in Las Vegas when a locomotive, used to switch the order of railroad cars at a Union Pacific Railroad yard overturned on top of two Calnev pipelines. About 8:30 AM, leading 9 cars and trailing 12 cars derailed. A pipeline on one side contained jet fuel and on the other gasoline. Both were buried 4 to 5 feet below ground.

Santa Fe Pipeline Company (formerly Southern Pacific Pipelines Company) advised that 55% of its 3,300 mile pipeline was installed along railroad rightsof way; between 1966 and 1989, 121 train derailments had occurred over pipeline. [Not included in Sandia's probability calculations.]

NTSB91 Cars loaded with styrene monomer, acrylonitrile, acrylic acid, petroleum naptha and a mixture of chlorosilanes, including trimethylchlorosilane. Styrene and acrylic acid are flammable, corrosive and can polymerize, releasing heat in the process. Acrylonitrile and trimethylchlorosilane are flammable liquids, corrosive and difficult to extinguish. The latter forms hydrochloric acid in the presence of water.

NTSB69 A 37 foot section was propelled 1000 feet in the air from the wreck, bouncing several times and coming to rest 1600 feet from the wreck center. A 37 foot section was propelled 800 feet from the wreck, striking the peak of a roof, then bounced to about 1100 feet from the wreck.
Must try to determine initial velocity and energy.

NTSB71a The derailment was due to movement of the rail caused by lateral forces. The cause of the complete failure of the tank car was due to its being struck by the coupler of another car and the brittleness of the tank car steel at $4^{o}F$. [These two types of events could occur with a spent fuel cask.]

NTSB71b A derailment occurred before the arrival of a passenger train and obtsructed the tracks. [This type of accident could occur with a spent fuel rather than passenger train.]

NTSB72a This accident shows that electric lines are often located next to tracks, particularly in small towns. If electric lines are involved in an accident, loss of electric (and phone) can prevent fire crews from fighting a fire and contribute to the resultant damage. Also, uncoordinated fire response.

NTSB76a
NTSB77 Crew physically fit, adequate rest, ample experience. Just a little fog and complacency. The cars were loaded with butadiene, vinyl chloride, tetrahydrofuran, propylene oxide.

NTSB76b The speed of BM-7 was not listed in the NTSB rpt, but if it assumed 35 mph, the same as for NY-12, the two trains collided at a relative speed of 70 mph.

NTSB76c The coupler penetrated the trailers main frame rail 8 feet from the rear of the trailer, about 3 ft above ground level. The train was going 60 mph. [Is the height of the coupler, 3 ft, about equal to the height of a truck shipping cask?] In this accident, it was not the train undercarriage, but the train sheet metal structure and corner post which struck the truck.

NTSB72b The number of injuries in this head end collision was due in part to he decision of the firemen to fight the fire, the failure to notify emergency personnel of the hazard and **inquisitive nature of bystanders**.

NTSB73 Truck struck a rock outcropping alongside the road. [How probable is it to have such rock outcroppings which present an impenetrable object?]

NTSB74 The average accelerationsin this case were 7.5g because the bus frame was collapsing. This would not be the case if the object were a spent fuel cask.

NTSB68 Of 31 vehicles, 23 vehicles had been recovered 16 days after the accident. Derrick boats equipped with clamshell buckets. This shows recovery operations with this kind of accident can take quite some time, weeks. This accident also relates to the discussion of other bridge collapses and the number of deficient bridges in the U.S.

NTSB83 Fire burned for 2 hrs 40 minutes. 8800 gallons of gasoline. 5000 gallon storm drain tank located below roadway had valves closed to prevent leakage of burning gasoline. Thus, fuel was trapped beneath tunnel. This scenario disproves the assumptions made in 1977 Sandia report about spread of fuel and length of time fire could burn.

On April 28 and 29, 1982, CalTrans conducted traffic volume counts: 63,700 vehicles traveled the westbound route daily; of the 1126 trucks, 26, including 8 flammable materials tankers, carried hazardous materials. This gives some idea of the hazardous material frequency. 39 accidents occurred over a 3-yr period. One can determine the accident probability, # accidents per mile from volume and distance measurements.

CalTrans conducted an analysis of the fire development:

- Examination of copper wires, aluminum castings, plastic light covers and signs, glass, glazed tile and concrete spalling as well as various component metals of the burned vehicles at different heights above the road provide a minimum and maximum temperature determination at various points in the tunnel.
- The upper levels in the tunnel experienced a T of 1914 ± 35 ^{O}F near the origin of the fire. The near the roadway was 1650 ^{O}F.
- T above 1190 ^{O}F at the ceiling extended as far east as station no. 22, where they dropped below 1116 ^{O}F to station no. 27 at the east entrance. The heat became more stratified as it moved toward the east entrance. The vehicles further east were exposed to T of 1400 ^{O}F to 1600 ^{O}F above the vehicle headlight level and red copper oxide on some vehicle wiring indicated T as high as 1900 ^{O}F supported by the burning of fuel in these vehicles.
- The air flow into the tunnel at the west end was 15.5 mph, over the hottest portion of the fire between station no. 14 and 18, it was 71 mph with a gradual reduction to about 32 mph at the east entrance.

C Saricks and T Kvierck, *Trends in State-Level Freight Accident Rates: An Enhancement of Risk Factor Development for RADTRAN,* Argonne National Laboratory, ANL/CP-73863, 1991

Objectives of the study are to update the accident risk factor data base for 1985, with 1986 through 1988 data for specific classes of carriers used to haul spent fuel: interstate registered highway contract carriers, member railroads of the Association of American Railroads and interstate barge lines.

Highway Interstate Carrier Combination Trucks

Data base of accidents is from the Office of Motor Carriers, *50-T Master File of Accidents of Motor Carriers of Property*, US Department of Transportation. It is based on carrier-submitted reports. Data base of miles traveled is from FHWA's, *Highway Statistics*. Developed from fuel sales data, vehicle counts by official 24-hour counting stations. About 13% of all truck miles is by combo rigs.

Rail Transport by Freight Train Railcars

Accident data is the annual *Accident/Incident Bulletin* compiled by DOT's FRA Office of Safety. The denominator is total railcar-kilometers moved per unit time by state. Developed by ICC from shipping manifests.

Especially high accident rates for rural truck travel are reported in Connecticut, Massachusetts and New Jersey. Especially high accident rates for interstate truck travel in general reported in New Jersey and New York. The highest fatality rates occur in North Carolina. High urban accident rates on interstates occurred in Illinois, Maine, Montana, New Mexico and South Dakota.

Tables 1 and 2 give the accident rates for highway and rail, respectively.

Table 1. Highway Combination Truck Accident,Fatality, and Injury Rates Based on Reportable Interstate Carrier Accidents, Reported Fatalities & Injuries, And Estimated Flows, 1986-88

(10^{-7} Accidents and Injuries Per Shipment-Kilometer, 10^{-8} Fatalities Per Shipment-Kilometer)[a]

	Accident Involvement Rates				
State	FAI-U	FAI-R	FAI	FAP	FAS
AL	4.68	1.26	1.85	5.16	3.96
AZ	2.71	1.60	1.76	2.12	1.45
AR	4.82	1.73	2.09	4.69	6.84
CA	1.92	1.64	1.76	1.15	2.22
CO	6.28	2.76	3.60	4.11	4.42
CT	2.67	4.60	3.23	2.56	9.09
DE	2.56		2.56	7.35	4.81
FL	2.25	1.21	1.50	3.73	6.33

GA	4.87	1.65	2.28	6.15	4.04
ID	1.73	2.30	2.22	4.93	2.29
IL	8.75	1.76	3.53	6.40	1.78
IN	4.58	1.92	2.43	4.72	2.80
IA	3.54	1.78	2.02	4.03	1.24
KS	4.48	2.04	2.56	5.11	1.38
KY	5.13	1.46	1.99	5.74	8.80
LA	3.54	1.30	1.88	3.53	2.39
ME	9.03	2.44	2.93	5.44	2.28
MD	3.08	3.95	3.46	3.56	12.4
MA	1.42	6.47	2.68	3.43	46.1
MI	3.16	1.59	2.12	2.68	0.81
MN	2.66	2.06	2.29	4.19	2.16
MS	2.01	1.19	1.35	4.48	0.65
MO	5.18	1.78	2.61	5.36	2.49
MT	10.00	2.52	2.89	5.38	1.02
NE	6.97	1.77	2.09	3.62	0.99
NV	6.33	1.57	1.97	4.35	3.17
NH	0.22	1.39	1.18	4.36	3.33
NJ	2.77	7.65	4.24	6.80	9.69
NM	9.64	1.92	2.35	4.77	12.2
NY	5.69	2.93	3.98	3.16	9.48
NC	5.92	2.28	2.97	5.17	6.37
ND	4.40	0.99	1.18	1.99	0.40
OH	3.16	2.27	2.52	4.42	11.0
OK	3.76	1.47	1.91	3.61	1.73
OR	3.99	2.20	2.48	4.17	1.63
PA	3.02	3.60	3.48	7.21	7.92
RI	2.27	1.98	2.16	1.37	16.70
SC	3.13	1.83	1.99	6.27	2.27
SD	8.57	2.09	2.18	3.94	1.49
TN	7.97	1.48	2.48	5.56	6.26
TX	2.74	1.56	2.00	2.78	1.09
UT	2.52	2.41	2.44	3.70	5.00
VT	0	1.38	1.33	6.30	6.80
VA	2.63	2.54	2.56	4.67	5.03
WA	1.61	2.50	2.10	2.62	0.73
WV	2.95	3.10	3.07	11.70	7.87
WI	5.29	1.74	2.18	2.80	3.24
WY	2.98	3.42	3.40	3.41	3.7
USA	2.58	2.03	2.44	3.94	3.48
$\sigma=$	2.36	1.25	0.69	1.77	6.98

where FAI-U, FAI-R and FAI are the urban, rural and overall interstate accident rates and FAP and FAS are the accident rates for primary and secondary roads.

Table 2. Total and Mainline Only Reportable Railroad Freight Car Accidents on Carrier-Owned Track
Estimated Car-Kilometers for 1986,1987,and 1988, with Accident Rates by State for 1986,1987,1988 and 1985/8 Combined
(Rate Unit is 10^{-8} Accidents per Railcar-Kilometer)

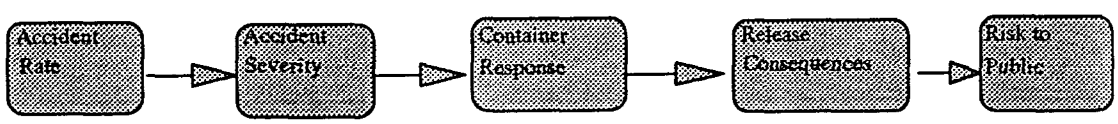
	Railfreight Accident Rates							
		1986		1987		1988		1985-8
State	Tot.	Main Only	Tot.	Main Only	Tot.	Main Only	Tot.	Main Only
AL	3.88	2.00	4.80	3.37	4.13	2.52	4.80	2.75
AZ	1.40	1.05	1.30	1.08	1.44	1.18	1.75	1.30
AR	5.05	2.59	4.27	2.32	8.34	3.94	6.78	3.54
CA	5.10	2.64	3.30	1.98	4.32	2.30	5.10	2.51
CO	1.44	1.01	0.86	0.40	2.55	1.51	1.73	1.02
CT	26.47	17.65	16.67	8.34	24.95	0	28.27	10.10
DE	27.44	9.15	25.23	16.82	18.04	18.04	17.71	11.07
DC	0	0	316	316	0	0	117.09	78.06
FL	2.86	2.12	3.90	1.90	4.16	2.38	4.02	2.21
GA	6.44	3.08	6.77	2.81	6.18	2.69	6.44	2.84
ID	5.90	5.25	6.74	4.10	9.03	3.99	7.01	4.14
IL	11.70	3.10	9.97	3.10	9.08	2.45	10.67	2.97
IN	4.18	1.85	3.71	1.48	3.80	1.44	4.64	1.93
IA	17.63	7.15	12.72	6.65	11.95	7.01	14.67	7.16
KS	3.01	1.62	2.97	1.55	4.09	1.98	3.61	1.75
KY	4.78	2.39	3.77	1.98	3.60	1.84	4.48	2.44
LA	12.67	5.98	7.07	2.02	11.94	3.92	12.37	4.28
ME	28.22	16.93	29.40	13.36	52.57	26.29	37.80	18.53
MD	6.07	3.54	5.55	2.44	4.55	1.24	5.62	2.58
MA	12.33	5.87	10.06	3.71	7.31	2.81	11.65	4.97
MI	18.34	8.18	15.10	4.42	15.52	7.45	16.47	7.19
MN	8.63	2.64	6.24	3.30	7.86	3.63	8.48	3.16
MS	15.16	11.20	12.93	9.84	8.47	7.14	11.52	8.51
MO	4.59	2.12	3.60	1.87	5.05	2.87	5.28	2.56
MT	1.35	1.01	1.24	0.81	2.11	1.17	1.73	1.10
NE	4.04	2.11	4.81	2.49	4.46	2.23	4.63	2.56
NV	3.27	1.87	1.29	0.86	3.97	2.65	3.23	2.19
NH	6.60	6.60	17.52	11.68	24.27	16.18	21.45	17.16
NJ	13.86	2.64	9.44	5.31	10.10	4.75	12.38	4.82
NM	0.90	0.52	0.93	0.75	0.86	0.65	0.94	0.66
NY	7.23	3.92	6.80	4.14	7.26	3.36	8.32	4.30
NC	5.40	2.70	5.48	1.62	6.29	2.95	5.70	2.27
ND	2.18	1.48	2.43	1.86	1.49	1.12	2.41	1.80
OH	5.35	2.50	3.55	1.58	4.04	1.92	4.73	2.12

OK	5.25	3.01	3.52	1.90	3.77	1.88	4.66	2.72
OR	11.74	4.96	12.23	6.12	13.64	6.04	12.48	5.77
PA	4.86	3.73	4.22	2.37	3.54	1.95	4.38	2.69
RI	0	0	0	0	0	0	105.33	0
SC	4.64	2.16	4.74	3.62	5.03	3.71	5.11	3.31
SD	8.16	6.27	14.98	14.49	7.27	6.36	10.19	9.09
TN	4.88	1.69	4.67	1.89	7.56	2.02	5.59	1.88
TX	7.03	3.36	5.29	2.50	5.92	2.45	7.12	3.16
UT	3.69	1.34	1.85	0.93	11.19	4.04	5.78	2.31
VT	5.98	2.99	7.86	5.24	24.32	18.24	15.22	11.59
VA	4.27	1.42	4.39	2.31	4.59	2.15	4.35	1.91
WA	3.65	1.38	2.69	1.50	3.57	1.12	3.49	1.44
WV	11.49	9.23	9.97	7.73	6.08	4.67	9.61	7.42
WI	18.79	7.52	16.75	7.75	12.57	7.21	16.53	7.66
WY	2.55	1.37	2.61	1.47	2.88	1.40	3.10	1.97
TOT U.S.	5.51	2.63	4.70	2.36	5.14	2.43	5.57	2.66
					σ	=	21.48	11.12

Rock Slide, I-40, March 5, 1985

Must check whether Sandia accident analysis assumes rock slides and impacts into massive boulders. About 20,000 tons of rock blocked east and west bound tunnel bores of I-40, a route carrying more than usual number of nuclear shipments, down to Barnwell, SC and between the Savannah River Plant and Oak Ridge, Tenn. This involves a crash into a stationary object.

Simplified Risk Assessment Diagram



Discussed in this Study

SAND80-2124
EL Wilmot, *Transportation Accident Scenarios for Commercial Spent Fuel*, Sandia National Laboratories, February 1981

Uses fault-tree analysis to determine the amount of radioactive material released from fuel into cask, from cask into environment, assuming certain severe accidents. Three pages are devoted to determining the accident rates and probabilities. Assumes that fire and impact are independent variables, therefore multiplies the probabilities of severe accidents in each most severe category to get small probability. This is an error since 1% of truck fires occur with an impact (fires may also occur without impact). It is true that the <u>duration</u> of a truck or train fire is independent of whether an impact occurred.

NUREG-0170, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes,* Nuclear Regulatory Commission, December 1977.

First, determine probability of accidents at varying speeds. Place into different severity categories, I through VIII. These accidents are on an unyielding surface. Next, use a derating scheme to determine fraction of accidents in different severity categories on real surfaces. Do this in following manner. Break down country as a whole into surface types, and estimated land area for each surface type. Compare velocity (unyielding) with velocity (yielding) for each surface type. Thus, velocities in damage category VIII are distributed into other damage catgeories. This is based on nationwide average. With this method, airplane accidents become the following:

Aircraft Accidents

Category	Fractional Occurrence (Unyielding)	Fractional Occurrence (Yielding)
VIII	0.03	0.0003
VII	0.04	0.0046
VI	0.03	0.0194
V	0.03	0.0279
IV	0.05	0.0107
III	0.09	0.0434
I/II	0.73	0.8937

Next, break down accident severities into population density zones. [This method understates risk since most of the concrete is located in urban and suburban areas where more severe accidents occur.]

Memorandum

To: Bob Halstead

From: M Resnikoff, RWMA

Date: December 24, 1992

Subject: Status Report, "Severe Highway and Rail Accidents"

We have now reviewed 36 severe highway and rail accidents and other documents. A list of the documents reviewed and the Table of Contents of our report are attached. We have so far gathered 60 pages of notes and are now in the process of analyzing our results, putting them into a coherent form and drafting the report. A description of the accidents reviewed (≈60 pages) will be included in the Appendix of the report. Because the documents are still on order, the I-880 Oakland Freeway collapse in the Loma Prieta earthquake is still not definitively analyzed. Similarly, we have requested documents from the State of Idaho regarding direct impacts of semis into bridge abutments and associated bridge collapses, and the US Department of Transportation regarding overall accident statistics. In addition, we have requested a report by the Federal Railway Administration of a rail explosion (18 box cars of TNT) in Roseville, California, April 28, 1973.

We estimate that a rough draft of the report will be completed by the first week in January and that a draft for review by the Nevada Office of Nuclear Waste Projects will be completed by the end of January. We would like to request that the deadline for the report be extended another month, to the end of January.

As part of the presentation of the results of our study, we would like to develop a simulation of three severe accidents in a sequence of slides or videotape. This is not part of the original proposal. Please inform us if the Nevada Office of Nuclear Waste Projects has an interest in this extension of our project.

Calnev Pipeline Explosion and Las Vegas

Note: the May 12, 1989 derailment of the Southern Pacific Transportation Company freight train and subsequent rupture of the Calnev petroleum pipeline in San Bernardino, California 13 days later has important implications for Las Vegas. The same pipeline extends to Las Vegas. Santa Fe Pipeline Company (formerly Southern Pacific Pipelines Company) says that 55% of its 3,300 mile pipeline was installed along railroad rights of way; between 1966 and 1989, 121 train derailments had occurred over the pipeline.

A similar accident occurred June 27, 1989 in Las Vegas when a locomotive, used to switch the order of railroad cars at a Union Pacific Railroad yard overturned on top of two Calnev pipelines. About 8:30 AM, leading 9 cars and trailing 12 cars derailed. A pipeline on one side contained jet fuel and on the other gasoline. Both were buried 4 to 5 feet below ground.

Documents Reviewed for Nuclear Waste Project Office, State of Nevada

Combined

Eggers83 Eggers, P, *Severe Rail and Truck Accidents: Toward a Definition of Bunding Environments for Transportation Packages,* prepared for Nuclear Regulatory Commission, NUREG/CR-3499, October 1983.

Fischer87 Fischer, LE, *et al, Shipping Container Response to Severe Highway and Rail Accident Conditions: Main Report (Technical Report),* Lawrence Livermore National Laboratory, NUREG/CR-4829-v1, February 1987.

Kanipe92 Kanipe, FL and KS Neuhauser, *RADTRAN 4: Volume 4, Programmer's Manual,* Sandia National Laboratories, SAND89-2370, July 1992.

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Explosion

NTSB71a *Chicago, Burlington and Quincy Railroad Company Train 64 and 824, Derailment and Collision with Tank Car Explosion, Crete, Neraska, February 18, 1969*, National Transportation Safety Board, NTSB/RAR-71/2, 1971.

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NTSB75 *Southern Pacific Transportation Co. Freight Train 2nd BSM 22 Munitions Explosion, Benson, Arizona, May 24, 1973*, National Transportation Safety Board, NTSB-RAR-75-2, 1975.

NTSB76a *Burlington Northern Inc Monomethylamine Nitrate Explosion, Wenatchee, Washington, August 6, 1974*, National Transportation Safety Board, NTSB-RAR-76-1, 1976.

NTSB83b *Railroad Accident Report - Derailment of Southern Pacific Transportation Train No. 01-BSMFF-05 Carrying Radioactive Material at Thermal, California, January 7, 1982*, National Transportation Safety Board, NTSB-RAR-83-1, 1983.

NTSB87 *Collision Between a Tractor-Semitrailer Transporting Bombs and an Automobile Resulting in Fire and Explosions, Checotah, Oklahoma, August 4, 1985*, National Transportation Safety Board, NTSB/SIR-87/01, 1987.

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NTSB72a *Penn Central Transportation Co Freight Train Derailment, Passenger Train Collision with Hazardous Material Car, Sound View, Connecticut, October 8, 1970*, National Transportation Safety Board, NTSB-RAR-72-1, 1972.

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NTSB79c *Louisville & Nashville Railroad Company, Freight Train Derailment and Puncture of Hazardous Materials Tank Cars, Crestview, Florida, April 8, 1979*, National Transportation Safety Board, NTSB-RAR-79-11, 1979

NTSB 81 *Illinois Central Gulf Railroad Company Freight Train Derailment, Hazardous Material Release and Evacuation, Muldraugh, Kentucky, July 26, 1980*, National Transportation Safety Board, NTSB-RAR-81-1, 1981.

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NTSB90b *Derailment of Southern Pacific Transportation Company Freight Train on May 12, 1989 and Subsequent Rupture of Calnev Petroleum Pipeline on May 25, 1989,* San Bernardino, California, National Transportation Safety Board, NTSB/RAR-90/02, 1990.

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Mountaineer85 Newclips, I-40 Rockslide, March 5, 1985, The Mountaineer, Waynesville, N.C., 1985.

NTSB67 *Collapse of US 35 Highway Bridge, Point Pleasant, West Virginia, December 15, 1967,* National Transportation Safety Board, NTSB-SS-H-2, 1967.

NTSB74b *Greyhound Bus Collision with Concrete Overpass Support Column on I-880, San Juan Overpass, Sacramento, California, November 3, 1973,* National Transportation Safety Board, NTSB-HAR-74-5, 1974.

NTSB74c *Automobile Crash Off the Silliman Evans Brdige, I-24/65, Nashville, Tennessee, July 27, 1973,* National Transportation Safety Board, NTSB-HAR-74-2, 1974.

NTSB 76c *Head-On Collision of Two Penn Central Transportation Company Freight Trains Near Pettisville, Ohio, February 4, 1976*, National Transportation Safety Board, NTSB-RAR-76-10, 1976.

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NTSB90a *Collapse of the Northbound US Rte 51 Bridge Spans over the Hatchie River near Covington, Tennessee, April 1, 1989*, National Transportation Safety Board, NTSB/HAR-90/01, 1990.

Appendix

NTSB-RAR-79-11
Louisville & Nashville Railroad Company, Freight Train Derailment and Puncture of Hazardous Materials Tank Cars, Crestview, Florida, April 8, 1979

About 8 AM on April 8, 1979, 26 placarded cars (of 29 car train) containing hazardous materials, of Louisville and Nashville Railroad Co freight train derailed while moving around a 4^{o} curve between Milligan and Crestview, Florida. Tow tank cars of anhydrous ammonia ruptured and rocketed. Twelve other cars containing acetone, methyl alcohol, chlorine, carbolic acid and anhydrous ammonia ruptured and burned. 14 persons injured, 4,500 persons evacuated. Cause: excessive train tonnage and improper train handling. Released chlorine and anhydrous ammonia formed a cloud that threatened a 300-square mile area.

L&N train consisted of 5 locomotives and 114 cars (107 loaded, 6 empty and a caboose), including 67 cars containing hazardous materials. Total trailing weight, 11,360 tons. Crossed Yellow River Bridge, 43 mi south of Goulding Yard, train moving at 30 mph, entered a 4^{o} curve to the left. About 700' into the curve, throttle increased to prevent train from stalling on the 1 %, 5-mile long upgrade into Crestview. Train still moving about 30 mph when train's emergency brakes applied. Fires near the cars near the bridge. Train separated between 36th and 37th cars and several cars had derailed. Tanks cars were lying in line along outside of curve. A fire had started in tank cars jacknifed along tracks. About 8:03 AM the 59th car exploded, releasing a gas cloud and propelling a part of the car eastward. Local emergency personnel were notified. About 8:15 AM head brakeman met responding firefighters. He then uncoupled 35th car. Conductor (only conductor had waybill information) gave waybills and train consist to trainmaster who arrived at the scene about 8:30 AM. About 8:45 AM (45 min after accident) trainmaster gave information to firefighters.

The 59th car that contained anhydrous ammonia had been wedged between two adjacent cars. Car pinched. Crack propagated around the tank wall, separating the tank in two sections. One portion of the tank car rocketed east 650 feet; one portion west 250 feet.

The 56th car containing anhydrous ammonia derailed, rolled over and dislodged its dome housing cover. Its relief valves were damaged and the tank car stopped upside down on top of its relief vent. One end pointing up and the lower end engulfed in a ground spill of acetone and methyl alcohol released from other ruptured cars. Train embankment where flammable materials pooled. About 8:23 AM the 56th car exploded. Derailed cars 48 through 55 were engulfed in a bright yellow-orange fire, which continued to burn for about 60 hours, consuming the acetone, methyl alcohol and carbon tetrachloride. All the breached cars contained residues which slowly vented in the wreck area for 5 days. Phosgene gas wafted from carbon tet car. 17 derailed cars had a capacity of 33,500 gallons. Extensive fire damage within 130-foot radius of derailed and burning cars. All trees and ground cover extending for 650 feet northwest of the derailment site were defoliated by the ammonia cloud.

Crew consisted of locomotive engineer, head brakeman, conductor and rear brakeman. Class 3 track. Track relaid November 1976. FRA emergency order No. 11, February 7, 1979 required 30 mph speed restriction. On March 1, 1979, L&N requested relief from the order on two segments which it stated were in compliance with FRA regulations. The FRA lifted the emergency order on this segment April 6, 1979, 2 days before the accident. On March 9, 1979, FRA inspection using a FRA track geometry vehicle, indicated a deviation in crosslevel. L&N issued a 25 mph limit through the area. On April 1, 1979, the crosslevel defect was corrected and the speed limit raised to 35 mph. The track had been inspected ultrasonically for rail defects on March 28, 1979 and April 2, 1979 and no defects were noted. Normal train traffic is 4 trains in each direction.

Meteorological Information

At the time of the accident, it was daylight, visibility was about 7 miles and the T was about 57°F. The sky was about 80% overcast with clouds at 20,000 feet and moderate winds from the south at 5 mph, gusting to 20 mph.

Public Health Aspects

Despite the use of self-contained breathing apparatus and short work shifts, 10 wreck-clearing workers were overcome with fumes. Some were hospitalized. Sheriff and civil defense personnel evacuated several hundred people in the Town of Milligan and a 1-square mile area to the west of the derailment. When vapor cloud rose over 200 feet and began moving westward, evacuation area was extended 4.5 miles to the Town of Baker and involved over 1,500 residents. Information about the cloud observed by Air Force AC 130 aircraft. By 11:30 AM, evacuation area extended to include the entire northwest quarter of Oakloosa County, over 300 square miles and more than 4,500 residents. By noon the cloud extended 28 miles northward to the Florida/Alabama state line. During the next day the fire began to subside and the vapor cloud reduced to a height of 1,000 feet. The evacuation area was reduced from 13 miles to 4 miles downwind. Residents in the outward evacuation area were allowed to return home by 7 AM on April 10.

By 4:15 AM on April 11, the tank car fires had burned out between April 12 and 16, all hazardous materials transferred. On April 13 all residents were allowed to return home.

Accident Cause and Damage

36th car rear showed heavy contact marks from coupler shank. 39th car had a piece of outside rail driven through its trailing truck bolster. Train brakes and track indicated no pre-existing defects. Problem appeared to be length and tonnage of train through varying grades and curves. Could not computer model the accident. Part of the train coming down grade to Yellow River, and part of train ascending and passing through 4°curve. Thought to be large compressive forces between the 36th and 37th car, causing the 36th car to overturn the outside rail. As the wheels of the 39th car's leading truck derailed, the outside rail broke and was forced upward. The north end of the broken rail speared the trailing truck's bolster and the rail was pushed outwards.

Emergency Response

Emergency response network faulty. Officials should know within minutes after notification the extent of dangers. Early outbreak of fire lofted materials Sparsely-settled area. Allowed less casualties. During first day, communications with command post were extremely heavy. Lack of single emergency number for local personnel to call. Uncoordinated dispatching of experts to the scene. Federal and industry personnel sent to the scene were not dispatched by persons in command of emergency response operations. The use of the Air Force AC 130 aircraft with communication links to ground observers was essential.

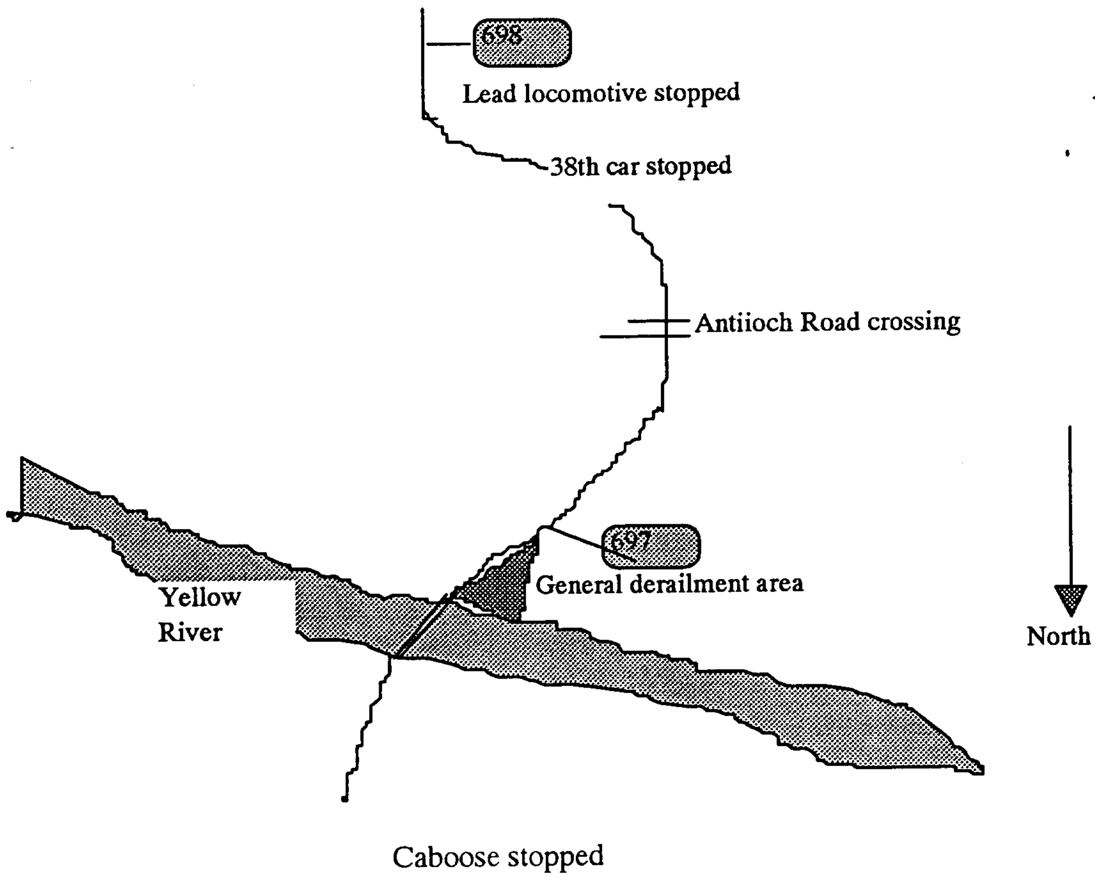


Figure 1. Louisville & Nashville Railroad Company, Freight Train Derailment and Puncture of Hazardous Materials Tank Cars, Crestview, Florida, April 8, 1979

NTSB-RAR-81-1
Illinois Central Gulf Railroad Company Freight Train Derailment, Hazardous Material Release and Evacuation, Muldraugh, Kentucky, July 26, 1980

About 7:58 AM on July 26, 1980, 4 locomotive units and 17 cars (38 trailing cars total), including 7 placarded tank cars containing hazardous materials were derailed while moving at a speed of 35 mph around a 6^{o} curve in Muldraugh, Kentucky (between Central City and Cecilia). Two tanks cars of vinyl chloride were punctured and their contents burned. About 6,500 persons were evacuated from Muldraugh and the US Army installation at Fort Knox.

The cause of the accident appears to be tipping of the outside rail and widening of the track gage in the 6^{o} curve because of the combined effects of defective crossties, excessively worn rail and the lateral forces caused by the train's speed.

About 18.7 miles from Cecilia, the train traveled down a 1.1% grade. The train left the descending grade, entered a 101 foot straight section and approached a 6^{o} curve to the right. At a speed of 26 to 30 mph, the crew members heard a popping sound and felt the lead unit fishtail as the rear of the lead unit derailed. The brakes were placed in emergency. All the locomotive units derailed and overturned. The following 17 cars derailed. 7 tank cars contained hazardous materials. Six contained vinyl chloride and one contained chlorine. Gas escaped and ignited. They went to a highway and advised a local police officer and advised evacuation. The conductor saw the gas cloud and advised military personnel at Fort Knox. The flagman radioed the train dispatcher and requested emergency aid.

The track was class 3. The curvature, superelevation and profile deviations were within the tolerances for class 3. Because of buckled track, ICG order no. 116 limited maximum speed to 30 mph. The track was checked twice a week. The FRA inspector cautioned the IGC track supervisor that the track was flaking metal with each pass. The curve was inspected on July 25, one day before the accident. A maintenance gang was scheduled to resurface the curve on July 28. The gang was scheduled to spike crossties and replace defective crossties. A train dispatcher, located in Chicago, has direct radio communication with trains moving through the accident area. An average of 45 trains per week operate over the single main track.

Meteorological Information

At the time of the accident, daylight, weather was clear, wind was calm and the T was 72^{o}F.

Public Health

Shortly after the derailment, crewmembers informed the Muldraugh police and Fort Knox military personnel. 6,500 persons were evacuated, including 4,000 military personnel. At about 8:25 AM, KY Division of Disaster and Emergency Services (DES) was called in by local authorities to implement an emergency response plan. A temporary command post with DES in charge was established about 3/4 mile from the site and was later moved to a bldg at Fort Knox. Three highways and the air space (3 mile radius, 10,000 foot ceiling) was closed to air traffic. The evacuation area was reduced from 2 miles to 1 1/4 miles. The US Army provided assistance throughout the emergency.

Accident Cause and Damage

All cars remained coupled during the initial run-in until the cars jackknifed. An inspection of the 7th care revealed a tear about 2 1/2 inches long and 1/2 inch wide at the center of the tank. A large burned area was noted in the 8th car where fire impinged for more than 72 hours. About 30% of the tank contents was vented through the safety valve. Computer simulation estimated the train operating at 36 mph, 6 mph over the speed limit.

The momentum of the four derailed locomotives caused it to move a distance of 428 feet, breaking rails, and tie plates and forcing the rails outward. The locomotives left the track structure and traveled an additional 219 feet before overturning. Many excessively worn tracks were noted in the area.

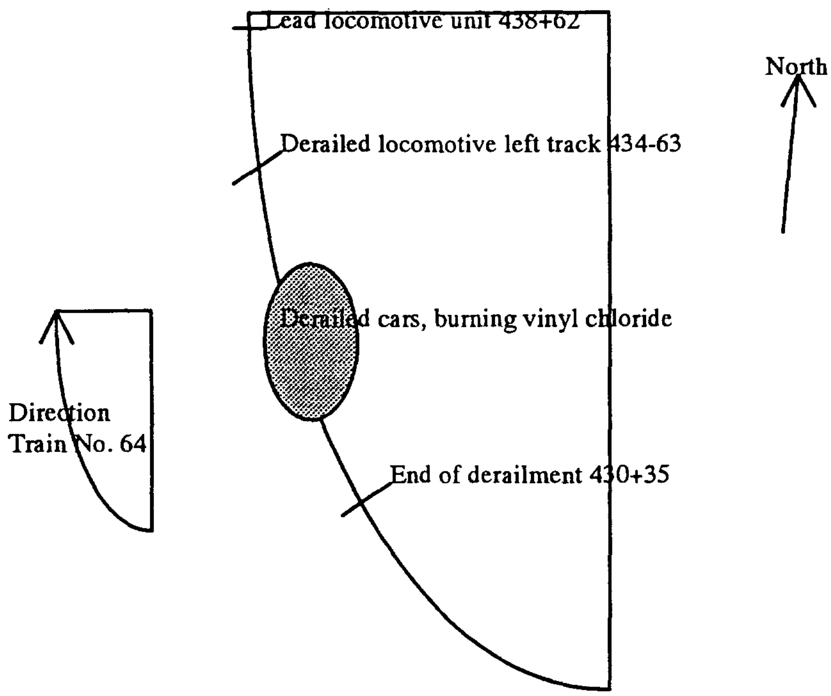


Figure 2. Illinois Central Gulf Railroad Company Freight Train Derailment, Hazardous Material Release and Evacuation, Muldraugh, Kentucky, July 26, 1980

NTSB-RAR-83-1
Railroad Accident Report - Derailment of Southern Pacific Transportation Train No. 01-BSMFF-05 Carrying Radioactive Material at Thermal, California, January 7, 1982.

About 9:50 PM on January 7, 1982, Southern Pacific Transportation Co freight train No. 01-BSMFF-05, derailed 14 cars at Thermal, California, while traveling 57 mph on the tangent single main track. Presence of radioactive material in the derailed Trailer-On-Flat-Car train discovered about 1 hour after the accident occurred. Accurate info regarding the precise nature of the radioactive material shipment not available at the accident site until 5 hours after the derailment. The rail was worn and company had neglected to inspect.

The train consisted of flat cars, originating in St Louis. At Hearne, TX, TTAX982525 added to train. The car had been transported to Hearne in local service from a piggyback ramp in Dallas, where two piggy back trailers had been loaded. One of the trailers contained, among other merchandise, a shipment of americium. The RAM had been tendered by the shipper at its facility in Houston to a motor carrier company, which consolidated the RAM with other materials at its Grand Prairie, TX facility. RAM was not listed on the company's manifests.

Shortly before 9:50 PM train with a 5-unit locomotive and 56 cars was approaching Thermal on the single main track. At milepost 620.2, a color signal flashed red, then green. Engineer prepared to reduce speed to enter switch at 618.49. Train's automatic air brakes went into emergency. Locomotives and head 36 cars remained coupled and came to a halt. The following 13 cars, all with highway truck trailers, derailed. No fire. At 9:55 PM, the chief dispatcher in San Francisco notified the Riverside County Sheriff's office and requested emergency services for transients injured in the accident. Emergency medical and firefighting personnel arrived at 10:15 PM. The Riverside County Fire Chief inquired about and was informed there was no hazardous material. About 10:30 PM, emergency personnel began searching for injured.

After the fire chief left the caboose, the conductor began reviewing the individual waybills for the derailed cars. Shortly before 11 PM, he noted RAM, Fissile Class III on the 48th car. The police dispatcher contacted the Radiation Health Unit of the Division of Occupational Safety and Health (DOSH) and was told to have "everyone stay back 100 yards, since there was no fire, and keep people there until a determination of radiation danger could be made." DOSH dispatched a health physicist to Thermal. At 11:13 PM, CHP closed off 6 miles of state highway no. 111. Following communications between the conductor and dispatcher, tracked original shipper about 1:00 AM, who informed SP of the actual quantity and form of the americium. Radiological monitoring devices were brought about 2:00 AM and no contamination was found. The DOSH representative arrived at 3:00 AM. At 4:00 AM, all concerned personnel were notified and the state highway was reopened. The radioactive placards were located about 5:00 AM. The truck trailer, on car 48, carrying americium was destroyed and their lading was badly damaged.

The track met or exceeded class 5 track, with a 55 mph limit for freight.

Meteorological Information

Visibility was good, T was 39^{o}F and the winds were from the north at 8 knots.

Public Health

The Ram consisted of 16 Ci of Am-241 and Be in mixture to be utilized in oil well exploration. The container consisted of a welded mild steel closed cylinder, about 20 inches long and 17 inches in diameter. An inner 2 inch diameter stainless steel tube contained a pressure vessel. The interior void was filled with polyethylene, a neutron absorber. Gross weight was 155 lb. The outer container had no damage.

Four transients on the deck of the flat cars were injured, and one died.

NTSB/RAR-83/05
Derailment of Illinois Central Gulf Railroad Freight Train Extra 9629 East (GS-2-28) and Release of Hazardous Materials at Livingston, Louisiana, September 28, 1982

About 5:12 AM on September 28, 1982, Illinois Central Gulf Railroad (ICG) freight train extra 9629 East derailed 43 cars (a total of 84 loaded cars and 16 empties plus a caboose) on the single line main track in Livingston, Louisiana. The train has a trailing weight of 11,022 tons and about one mile long. Most of the empty cars were scattered throughout the rear, with 4 just ahead of the caboose. Of the derailed cars, 36 were tank cars, 27 of these containing toxic or hazardous commodities and 5 contained flammable petroleum products. A total of 20 tank cars were punctured or breached in the derailment. Fires broke out in the wreckage. Thermally-induced explosions of two tank cars that had not been punctured caused them to rocket violently. About 3000 persons living within a 5-mile radius of the derailment site were evacuated for as long as two weeks. 19 residences and other buildings in Livingston were destroyed or severely damaged. More than 200,000 gallons of toxic chemical product were spilled, requiring extensive excavation of contaminated soil and its transportation to a distant dump site. This has resulted in long-term closure of the railroad line and an adjacent highway.

The likely cause of the accident was the disengagement of a worn air hose coupling which initiated the emergency brakes, and improper handling by the person at the controls. Apparently the engineer was drunk and an unqualified person was at the controls.

An operator-clerk was at the throttle at Livingston. The train was at full throttle. The locomotive bottomed out. Three or four seconds later it bottomed out again and the emergency brakes went on. After the head end stopped, the operator-clerk looked to the rear and saw a small fire which suddenly became a huge fireball. At 5:13 the conductor saw an explosion and instructed the engineer to radio the dispatcher. The engineer radioed the Hammond District dispatcher that "The whole world's on fire."

The 16th through the 58th head cars had derailed along the main track for a distance of 750 ft at milepost 26.8 The 26th through 32nd car were tank cars with vinyl chloride, a flammable gas. Two were breached in the derailment, creating the fireball which extended 400 ft from the south margin of Hwy 190 across the derailment site to 250 ft north of the track, enveloping a brick house. The fire chief arrived between 5:15 and 5:20 AM. By 5:30 AM the fire chief saw a pressure fire developing and began a house-by-house evacuation of 1,260 residents. The mayor was doing the same. Later the Louisiana State Police undertook the coordination of the response and evacuated 2,700 persons within a 5-mile radius.

75 tank cars, 7 of which were empty. A total of 55 tank cars were placarded as follows:

Placard	Derailed	Not Derailed
Chlorine	0	1
Flammable Gas	8	6
Flammable Liquid	1	6
Flammable Solid	1	0
Poison	4	1
Corrosive	14	14

A fire ball ignited oil leaking from the 22nd and 23rd cars. Vinyl chloride gas venting from the 30th and 31st cars burned as well as styrene monomer and toluene diisocyanate leaking from the 52nd and 54th cars. The fires fed by vinyl chloride and plastic pellets pressurized the 27, 28 and 32 cars which began to vent and burn. The fire became so intense that the 36th car, loaded with motor fuel anti-knock compound, exploded about 19 hours after the derailment, propelled into the pine grove north of the derailment. A second explosion occurred 82 hours following the derailment. The south tank head of the 29th car, loaded with vinyl chloride, was propelled 225 feet south. Most of the tank rocketed 425 feet north. Airborne fragments set fire to a 55-foot mobile home 500 feet south of the derailment site. Other parts traveled as far as 1,500 feet south.

On October 4, concern over the stability of burning styrene monomer prompted emergency personnel to extinguish the fire and demolish the car with explosive charges the next day. On October 11, 6 vinyl chloride cars were detonated. In all, 36 cars were destroyed. The car chemical products lost:

Commodity	**Gallons**
Vinyl chloride	163043
Styrene monomer	23145
Motor fuel anti-knock compound	5666
Toluene diisocyanate	2259
Phosphoric acid	148552

hydrofluosilicic acid	19780
Sodium hydroxide	15363
Perchloroethylene	14028
ethylene glycol	20840

Most of the chemicals not burned were captured from catch basins and diked drainage ditches. More than 100 truckloads of recovered and neutralized chemicals were transported to designated dump sites. More than 60,000 cubic yards of soil were toxically contaminated and trucked 150 miles to a dump site. Extensive scorching of trees, etc within a 1000 foot radius of the derailment.

The brakeman and engineer had 3 drinks each, plus a 5th of bourbon. The engineer had trouble talking. The engineer continued to drink until the accident. All train crew had been disciplined many times for rules infractions, which are spelled out in the report.

Speed is restricted to 35 mph on that section.

Meteorological Information

Clear skies with fog, ground visibillity of 2 miles, T of 57^{o}F and northeasterly winds at 4 mph.

Emergency Response

Accident occurred at 5:12 AM. Abut 6 AM LSP hazardous material specialists meet at temporary command post in courthouse. At 6:30 AM, LSP tactical unit with mobile command and helicopter arrive. At 8:30 AM, main command post set up further away. At 11:30 AM, Lieutenant Gov declares Livingston a disaster area, empowering LSP to remove residents. At 6PM evacuation zone enlarged (24-sq mi area, 2700 persons). At 9:30 AM Sept 29, initial team enters derailment site. At 2 PM on September 30, fires intensify and vinyl chloride cars begin venting through relief valves. On October 11, evacuation area reduced to within 2 block radius of derailment site. On October 16, IGC removes last derailed cars. Livingston had no emergency response plan. Serious complications would have arisen if the accident occurred later, when the school was in session.

Accident Cause and Damage

The train was traveling 39.2 mph. Equipment problem was the air hose coupler. It was dragged when not attached to trailing cars and was badly worn. Wheel marks on one of the cars indicated that the truck was off center and had been in contact with the car for a considerable period of time before the derailment. The car surfaces had heated to 600^{o}F. Eyewitnesses saw sparks. Computer simulations show the train was going at 51 mph at the derailment site. Buff forces exceeding 240,000 pounds were registered between 12th and 23rd car. Estimated 345,000 pounds maximum buff force at the 23rd head car, 17 seconds after the brakes applied. These unstable dynamic forces were too great for the train to remain on track. Other simulations indicated 45 mph at the derailment site and a stopping distance of 1,700 feet.

The bottoming out occurred near a culvert. The location was a chronic soft spot with visible pumping of mud.

NTSB/HAR-85/02

Collision of Isle of Wight County, Virginia Schoolbus with Chesapeake and Ohio Railway Company Freight Train, State Route 615 Near Carrsville, Virginia, April 12, 1984

About 3:25 PM on April 12, 1984, a westbound Chesapeake and Ohio Railway Company freight train traveling about 49 mph struck the front side of a northbound 1980 Isle of Wight schoolbus stopped at a railroad grade crossing on State Route 615 near Carrsville, Virginia. The weather was clear; the train whistle and bell were sounding before the collision. There were crossbucks on both sides of the single track. The driver's sight distance of the approaching train was 1/3 mile. The 64-passenger schoolbus body separated from the chassis on impact, rotated clockwise 180 degrees, rolled over 270 degrees and came to rest on its left side about 80 feet southwest of the crossing. Only two of the 26 school-aged children were injured seriously, but the bus driver was seriously injured and died five days after the accident. The probable cause of the accident was the bus driver's failure to stop before driving onto the railroad crossing to determine that it was safe to proceed.

The train crew observed the bus enter the tracks without checking for an oncoming train. The bus stopped on the tracks. When the train was 500 feet from the crossing, the engineer put the train into emergency braking. The train traveled an estimated 1980 feet west of the crossing before it stopped. It did not derail.

Emergency personnel were notified at 3:27 PM and arrived at the scene at 3:34 PM. The last victim was transported to the hospital at 4:45 PM.

The bus driver had 7 1/2 years experience and would have seen the train 25 seconds before the collision.

The train had 108 cars (23 loaded, 82 empty) and 3 locomotives. The length was 6,685 feet and weighed 5,232 tons. The emergency brake was applied when the train was going 49 mph. The train's speed at collision was 44 mph and it took 69 seconds for the train to come to a halt after the emergency brake was applied.

NTSB/RAR-85/08

Vinyl Chloride Monomer Release from a Railroad Tank Car and Fire, Formosa Plastics Corporation Plant, Baton Rouge, Louisiana, July 30, 1983

At 3:45 AM on July 30, 1983, vinyl chloride monomer under pressure escaped from a railroad tank car at the loading facility within the Formosa Plastics Corp manufacturing plant. The released VCM was ignited and a large billowing fire ensued. The cause of the accident was an employee's failure to close the tank car liquid valves and purge the pressurized vapor return and loading hoses before disconnecting them. Contributing to the cause of the fire were the improperly seated excess flow valves.

VCM is a flammable compressed gas, easily ignitable, producing hazardous combustible gases composed of hydrogen chloride and carbon monoxide.

The tank car had a capacity of 24,859 gallons and a fully loaded weight of 90 tons. One fire burned for 120 hours.

NTSB/RAR-85/10
Denver and Rio Grande Western Railroad Company Train Yard Accident Involving Punctured Tank Car, Nitric Acid and Vapor Cloud and Evacuation, Denver, Colorado, April 3, 1983

About 4 AM on April 3, 1983, a Denver and Rio Grande Western Railroad Company switch crew was switching 17 cars in the North Yard in Denver, Colorado when a coupler broke on the fourth car, leading to a 150 foot separation between the 3rd and 4th car. The engineer accelerated and plowed into a loaded car ahead at a speed of 10-12 mph. Upon impact, the end sill of the fourth car, an empty box car, over-rode the coupler of the loaded tank car and punctured the tank head. Nitric acid spilled from the car, formed a vapor cloud which dispersed over the area. As a result, 34 persons were injured and 9,000 persons were evacuated from the area. The fire department arrived at 4:12 AM. But at 4:23 AM, the Denver Hazardous Materials Coordinating Chief arrived on the scene and called off the firefighters. They withdrew to a safe distance - 1200 feet. Seven cars of soda ash were located, 780 tons and arrived at 11 AM. A snow blower spread the soda ash, and it took about 1 1/2 hours.

The coupler between the loosened cars had failed completely.

NTSB/RAR-86/01
Collapse of the US 43 Chickasawbogue Bridge Spans Near Mobile, Alabama, April 24, 1985

About 2:01 PM on April 24, 1985, two 34-foot long twin spans at the south end of the Chickasawbogue Bridge on US 43 about 2 mi north of Mobile fell into the water after a steel H-pile bent. Two of three southbound vehicles on the bridge stopped before reaching the edge of the bridge void. One vehicle, traveling about 40 mph, became airborne, struck one of the falling bridge spans and entered the water. The lone occupant exited the van and swam to shore before the van sank in 20 feet of water.

The collapse occurred during a time of low traffic. The bridge has a daily volume of 20,000 vehicles.

The cause of the accident was severely corroded H-pile near the mud line of the creek. None of the underwater elements of the bridge had been inspected since Nov 1969, though bridge inspected on 2-year intervals (and 21 days before the collapse). Earlier, at 1:55 PM, a motorist traveling on the southbound lanes had noticed that the bridge was sagging at the south end. He drove about 1.5 mi south to the police department. The Chief of Police drove northbound, saw a section of the bridge was missing and blocked all northbound traffic with his police car. He yelled to the driver on the soutbound side to do likewise.

Bridge opened in 1958. The bridge had an estimated design life of 75 years. The 450 foot long bridge had 12 individual twin spans, 11 of which were 34 feet long and 1 main span was 72 feet long. The north and southbound spans were 1 inch apart laterally and supported by the same steel pile bents.

In 1984, the FHWA reported there were about 574,045 highway bridges on public roads. 87% of these bridges were over water. Only 15 states routinely inspect the underwater elements. Corrosion had reduced the cross-sectional thickness by 54%. The FHWA has about 104 persons directly involved, and they devote 25% of their time to NBIS.

On June 28, 1983, a 10-foot long suspended span highway bridge over the Mianus River in Greenwich, CT collapsed and fell 70 feet into the river below.

Count of Deficient Bridges by State on Federal-Aid System as of December 31, 1984

State	Bridges in Inventory	Non-Deficient Bridges	Structurally Deficient	Functionally Obsolete	Defic Bridg
Alabama	7610	4521	1234	1855	3089
Alaska	569	511	41	17	58
Arizona	4384	4196	70	118	188
Arkansas	5806	3719	365	1722	2087
California	14803	12520	480	1803	2283
Colorado	3450	2855	392	203	595
Connecticut	2571	998	406	1167	1573
Delaware	444	398	26	20	46
Dist.of Col.	223	177	43	3	46
Florida	5538	4198	152	1188	1340
Georgia	7798	4970	821	2007	2828
Hawaii	656	523	86	47	133
Idaho	1661	1409	183	69	252
Illinois	10421	8319	1574	528	2102
Indiana	7039	3689	977	2373	3350
Iowa	7028	4688	847	1493	2340
Kansas	10619	6799	1005	2815	3820
Kentucky	4852	3511	329	1012	1341
Louisiana	5612	3815	901	896	1797
Maine	1257	1050	127	80	207
Maryland	2523	1758	345	420	765
Massachusetts	3597	2689	880	48	928
Michigan	5756	4686	808	262	1070
Minnesota	5020	4078	492	450	942
Mississippi	7456	4048	1728	1080	3408
Missouri	8580	5242	735	2603	3338
Montana	2504	974	166	1364	1530
Nebraska	5081	3698	738	645	1383
Nevada	762	667	6	89	95
New Hampshire	1202	875	168	159	327
New Jersey	3976	2797	786	393	1179
New Mexico	2849	2412	291	146	437
New York	8898	4232	3825	841	4666
North Carolina	5275	3153	517	1605	2122
North Dakota	1671	1253	190	228	418
Ohio	12151	10309	1616	226	1842
Oklahoma	7546	6061	770	715	1485
Oregon	4011	3428	334	249	583
Pennsylvania	10875	7954	2243	678	2921

Rhode Island	563	463	76	19	95
South Carolina	4198	3415	219	564	783
South Dakota	2785	2398	184	203	387
Tennessee	7114	4358	1205	1551	2756
Texas	25152	20287	1049	3816	4865
Utah	1417	1312	75	30	105
Vermont	1289	837	145	307	452
Virginia	6788	5311	586	891	1477
Washington	3935	3018	347	570	917
West Virginia	3351	1888	983	480	1463
Wisconsin	6218	3694	1695	629	2524
Wyoming	1895	1760	40	95	135
Puerto Rico	878	553	88	237	325
Total	**267657**	**192459**	**33389**	**41809**	**7519[illegible]**

* as of December 31, 1984
Source: NTSB/HAR-86/01, App. D

Count of Deficient Bridges by State Off Federal-Aid System*

State	Bridges in Inventory	Non-Deficient Bridges	Structurally Deficient	Functionally Obsolete	Defic Bridg
Alabama	7903	2471	3362	2070	5432
Alaska	266	158	84	24	108
Arizona	756	559	110	87	197
Arkansas	8530	1925	1666	4939	6605
California	7457	3610	1126	2721	3847
Colorado	3697	1270	2058	369	2427
Connecticut	1153	483	313	357	670
Delaware	247	181	25	41	66
Dist. of Col.	18	13	0	0	0
Florida	4467	2909	650	908	1558
Georgia	6393	2769	2890	734	3624
Hawaii	382	231	35	116	151
Idaho	1961	970	531	460	991
Illinois	14637	8496	4138	2003	6141
Indiana	10643	3591	3667	3385	7052
Iowa	19084	7211	5674	6199	11873
Kansas	15037	4305	5093	5639	10732
Kentucky	7632	3820	1993	1819	3612
Louisiana	8603	2914	3576	2113	5689
Maine	1335	738	310	287	597
Maryland	1536	821	217	498	715
Massachusetts	1179	515	631	33	664
Michigan	4645	2186	2053	406	2459
Minnesota	7886	4575	1395	1816	3211
Mississippi	9272	2357	5848	1067	6915
Missouri	15146	2361	4848	7937	12765
Montana	2273	421	683	1169	1852
Nebraska	11116	2368	6876	1872	8748
Nevada	249	175	28	46	74
New Hampshire	1349	345	422	582	1004
New Jersey	1756	975	498	283	781
New Mexico	571	308	151	112	263
New York	8521	1669	5704	1148	6852
North Carolina	10437	2255	4490	3692	8182
North Dakota	3804	1054	1957	793	2750
Ohio	16818	12363	2919	1536	4455
Oklahoma	14475	3942	7794	2739	10533
Oregon	2858	1875	372	611	983
Pennsylvania	10844	6181	3097	1566	4663
Rhode Island	126	79	33	14	47
South Carolina	4692	3378	897	417	1314

South Dakota	4276	1455	943	1878	2821
Tennessee	10996	4514	4775	1107	6482
Texas	18884	6109	7333	5442	12775
Utah	954	628	236	90	326
Vermont	1365	412	306	647	953
Virginia	5705	2868	531	2306	2837
Washington	2861	1996	334	531	865
West Virginia	3257	863	1726	668	2394
Wisconsin	6604	2772	2629	1203	3832
Wyoming	956	342	315	299	614
Puerto Rico	781	525	77	179	256
Total	**306388**	**121411**	**107419**	**77558**	**1849[illegible]**

* as of December 31, 1984
Source: NTSB/HAR-86/01, App. E

Collapse of the Thruway Bridge at Schoharie Creek, by Wiss, Janney, Elstner Associates and Mueser Rutledge Consulting Engineers for the New York State Thruway Authority, November 1987

NTSB/HAR-88/02
Collapse of New York Thruway (I-90) Bridge Over the Schoharie Creek near Amsterdam, New York, April 5, 1987

Shortly after 10:45 AM Sunday, a portion of the green steel and concrete bridge between two center pilings gave way after pier 3, which partially supported the spans collapsed. A tractor trailer and small car plunged directly into the creek. Shortly after, 2 others also fell in. A few moments later a westbound car fell in. Ninety minutes after the initial collapse, after troopers had removed people from the bridge, pier 2 and a third span collapsed. The Schoharie Creek, normally ten feet deep, had risen to 30 feet. The two portions of the bridge closest to the banks and the center pylons remained. A state trooper had crossed the bridge at 10:40 am. Nine bodies were recovered and a tenth, still missing, is presumed dead. At 10:48 am, the toll collector advised the Thruway Albany dispatcher. Troopers arrived at 10:50 AM from east and west directions.

The four passenger cars and the tractor-trailer were completely demolished. The roofs of the cars were smashed down to the dashboards. The tractor-trailer separated and came to rest about 300 feet apart downstream. The box type trailer was ripped open. One vehicle traveled about 4,700 feet from the bridge site.

Bridge opened in 1954, midway between Fultonville and Amsterdam at milepost 177.8. Total length of 540 ft between abutments and average height of 80 ft above Schoharie Creek. Before the bridge collapse, the region had a major storm during the week-end of April 3-5, 1987; 6 inches of rain fell in a 24 hour period. This rainfall together with significant amounts of snowmelt caused the waters of Schoharie Creek to rise to record levels. At 10:45 AM on Sunday April 5, two spans of the Schoharie Creek bridge collapsed. Span lengths between 100 and 120 feet. Schoharie Creek is underlain by alluvial material consisting of brown sand and well rounded cobbles. Also boulders that may be several feet in diameter and weigh 300 to 600 pounds.

Maximum measured flow in Schoharie Creek was 76,500 cfs on October 16, 1955, one year after the bridge was opened to traffic. Peak flow on April 5, 1987, was 64,900 cfs (which increased from 4,000 cfs in 24 hours). Average velocity of 10 to 12 fps. The recurrence interval for this type of flow is 1 per 70 years.

Collapse of spans 3 and 4 occurred suddenly. Spans 3 and 4 moved away from Pier 3 during the collapse. Caused by extensive undermining of the footing under Pier 3. Average velocity of the water at the time as great as 15 fps.

10 people died as a result of the bridge collapse. Four cars and a tractor trailer plunged off bridge. Other cars had stopped and drivers were looking over edge into water, when

troopers arrived on the scene and evacuated the bridge. Moments later, other sections of the bridge fell into the water. The bridge carries an average of 15,519 cars daily. The bridge was last inspected in April 1986, but the below water piles were not inspected.

The last bridge to collapse in NYS was a one land steel span in Hanover, Chatauqua County, Nov 14 1986. A truck and construction crew fell into Walnut Creek, 100 feet below.

63.6% of bridges in NYS are listed as deficient by the FHA. About 9 of 10 are structurally deficient. Nationwide, 243,300 bridges, or 42% of the total are deficient. But the bridge on the Thruway was listed as "good." 3 of 4 bridges in the US are 50 years old or more.

NTSB/RAR-86/04
Derailment of St Louis Southwestern Railway Company (Cotton Belt) Freight Train Extra 4835 North and Release of Hazardous Materials Near Pine Bluff, Arkansas, June 9, 1985

About 1:33 PM on June 9, 1985, St Louis Southwestern Railway Company freight train extra 4835 north derailed while passing over a ballast deck pile trestle located about 3.3 mi southwest of Pine Bluff, Arkansas. 18 of the 42 derailed cars were loaded tank cars and 14 of these contained regulated hazardous or toxic chemical commodities; 4 others contained non-regulated flammable petroleum. Fire broke out in the wreckage; two tank cars subjected to intense thermal exposure exploded. More than 2800 persons were evacuated from a 1-mile radius.

The probable causes of the accident were (1) failure to destress and adequately anchor the track to avoid longitudinal movement, (2) excessive speed and heavy braking on a downgrade approaching the accident location.

At 11:15 AM on June 9, 1985, northbound extra 4835 consisting of 6 locomotives, 93 cars and a caboose departed Eagle Mills to Pine Bluffs, a distance of 55 miles. At a point about 5 miles south of Pine Bluff and 1.9 miles south of bridge 272.14, extra 4835 north began descending a 1.7 mi grade with an average falling gradient of 0.74 percent. At the time the train was moving about 54 mph. Continual braking down the hill and increased the pressure at the bottom. The train was traveling 49 mph at the bottom the grade.

The fireman observed a lateral kink in the main track at a point 30 to 40 feet north of the south end of bridge 272.14 when the train's head end was 75 to 100 yards south of the kink. He estimated that both rails were 10 to 12 inches out of normal alignment to the left. Fully applied the brakes at that point. The locomotives and first 25 cars passed over the kink and did not derail. But when the locomotive was about 1/4 mile north of the bridge and moving about 41 mph, the train brakes went into emergency and cars began derailing at the bridge. The 26th through 56th cars derailed. Track movement caused derailment of the 15th through 25th cars that had already passed the kink.

Fire broke out immediately in the wreckage of 31 cars south of the bridge. Two tanks cars containing butyl acrylate, a combustible liquid, rupture and ignited. Burning liquid engulfed an insulated tank car loaded with liquid synthetic plastic and an insulated car containing ethylene oxide, a flammable liquid. Two derailed cars contained vinyl chloride and two tanks cars contained hydrogen fluoride anhydrous, a dangerous corrosive chemical.

The first fire crews were on the scene at 1:39 PM, 6 minutes after the accident. The conductor gave details of tank contents and instructions to the asst fire chief. For ethylene oxide, the recommended evacuation zone was 5000 foot radius. Rather than fight the fire, an estimated 2,840 persons were evacuated.

Initially the fire was caused by liquid butyl acrylate released from two punctured tank cars, but it spread rapidly to pelletized synthetic plastic that was spilled from four covered hopper cars, two of which were on top of the still intact ethylene oxide car. The car exploded at 6:40 AM on June 10, 17 hours after the accident occurred. A torch fire burned a large hole in one of the derailed tank cars containing liquid synthetic plastic (polymethylene polyphylisocyanate). This car burned and another filled with the same material exploded about 4:30 AM on June 11. After this, the fire diminished and unmanned fire hoses were set up by the fire department. The emergency was removed at 2:12 PM on June 15. Thus, fire lasted for two days, and emergency for six.

As a result of crushing impacts during the derailment and post-accident fires, 20 cars were destroyed or scrapped and 22 others were damaged. The contents of 31 cars were lost.

The train had a trailing weight of 10,548 tons and was 5,671 feet long. The track on this stretch was laid in 1967 and was due for replacement August 1985.

The weather was clear, calm and dry with a visibility of 10 miles.

Apparently when the train's brakes were applied at the bottom of the hill, the track ran ahead and buckled.

NTSB/RAR-89/05

Collision and Derailment of Montana Rail Link Freight Train with Locomotive Units and Hazardous Materials Release, Helena, Montana, February 2, 1989

About 4:30 AM on February 2, 1989, freight cars from, Montana Rail Link west bound train I-121-28 rolled eastward down a mountain grade and struck a stopped helper locomotive. Train 121: 3 helper units, 3 road units, 49 car train. 15 cars derailed including 3 tank cars containing hydrogen peroxide, isopropyl alcohol and acetone. Hazardous material released resulted in a fire and explosions. About 3,500 persons in Helena were evacuated. The probable cause of the accident was failure of the train crew to properly secure the train by applying emergency brakes when it was left unattended. Also the effect of extreme cold weather on the airbrake system.

Departed Laurel at 8:40 with 49 cars and 3 locomotives. The T at the time was -17^oF. The crew gad to be relieved at 1800 at Townsend, 29 mi east of Helena. A relief crew arrived at Townsend at 2330 to operate the train to Helena. They departed at 2355. Arrived in Helena at 310, Feb 2, 1989. Departed Helena at 3:20, with helper 2 in front. The local T was -27^oF. Train 121 approached Austin about 3:58, 13 mi west of Helena.

Switching maneuver: road units to go into lead and helper units to follow road units. Helper unit disengaged and moved into siding; road unit moved forward, but brakes on train not properly set. But the train, without locomotives, was gone. Recoupled locomotives and retraced steps eastward to look for trailing cars. They continued down the mountain at speeds 35 to 45 mph. Meanwhile Helper 1 had been called in and was proceeding westward. The locomotiveless cars and helper unit 1 collided. 21 cars involved and 15 derailed Engineer saw three tank cars, one was venting a whitish gray cloud. No flames sighted.

At 4:40 yard clerk saw orange glow. Clear liquid flowing in trackside ditch westward towards Benton Ave. Saw flames 2 feet high. First explosion occurred 3 to 4 seconds later. A second explosion occurred 1 to 2 seconds later. Flames 100 feet in the air. Second explosion was blue-white flash and loud noise. The crew of 121 was still traveling down the mountain and saw the explosion about 1 mi away. At 4:38 Helper 1 radioed the dispatcher in Missoula. A power outage followed resulting in loss of radio communications. Drove to police station Too busy. About 5:07 a yard office clerk contacted the MRL dispatcher from a mobile phone requesting hazmat info. About 5:13, 43 minutes after the accident, four HFD units were dispatched, arriving 5:19. The Acting Fire Chief was designated the Incident Commander at 5:20. About 6:00 an unmanned 3 inch deluge cannon was directed to cool the exposed tank cars. About 92 law enforcement personnel with 58 units were involved; 10 firefighting units with 20 personnel engaged from February 2 until the fire was extinguished about 10 on February 3.

The following communication problems: inability to use the radio repeater on Mount Helena for communications because of the power outage, delays in activating the Emergency Broadcast System (no one was manning the facility) and in contacting the local radio station because of disrupted telephone communications; and delays in obtaining information from various command posts on the nature of the accident and the chemicals involved.

On February 2, the mayor declared a local disaster and ordered an evacuation beginning 5:30. The initial evacuation was more than 1/2 mile radius, later reduced. By 10 on February 4, the evacuation was ended. About 3,500 people were involved. Extensive damage to a college dormitory.

49 cars of train 121 collided with standing helper 1; only 21 cars, of which 15 were derailed, were involved in general area of derailment. Damage to homes within 3 mile

radius of accident, including homes penetrated with fragments weighing several hundred pounds. Carroll College reported major damage to 10 buildings.

Heavy snow and low temperatures. At 5:51 T was -29^{O}F

All the hydrogen peroxide (18,950 gallons) and all the isopropyl alcohol were released. 38% of the hydrogen peroxide (7,300 gallons) in another tank car released. A mixture of hydrogen peroxide and molten polyethyelene could explode. Estimated force of second explosion equivalent to 10 tons of TNT (interaction between 9.1 tons of 70% hydrogen peroxide and 0.9 tons of polyethylene.

NTSB/HAR-90/01
Collapse of the Northbound US Rte 51 Bridge Spans over the Hatchie River near Covington, Tennessee, April 1, 1989

About 7:14 PM on April 1, 1989, moderate traffic on the northbound US Rte 51 bridge over the Hatchie River near Covington, Tenn. At that time, the river was above flood stage, covering the flood plain with 3 to 4 feet of water. At 7:15 PM a motorist encountered a depression in the bridge deck. About 8:10 PM a motorist traveling about 50 mph struck a v-shaped depression. About 8:13 PM a motorist struck a depression about 2.5 to 3 feet deep. About 8:15 PM, another motorist encountered a 3-foot depression. After traveling over the bridge, in his rear view mirror, the motorist saw two pairs of headlights then one disappeared from view. The motorist continued north 3 mi to Henning to report the incident. Concurrently a passenger car with two occupants was traveling northbound, encountered a deep depression and stopped after crossing the bridge and observed a vehicle behind them fall into a void where the depression had been. Shortly afterward, they watched several more vehicles and tractor trailer drive into the void.

Also about 8:15 PM, a driver and two passengers of a van were traveling about 50 to 55 mph northbound behind a tractor trailer that was preceded by two autos. The van operator began to move to the left to pass the truck when the truck suddenly moved into the left lane in front of the van. The trailer lights shifted from side to side and then disappeared along with the two autos ahead of the truck. The van operator stopped 12 feet from the edge of the bridge and observed the semi floating in the river. It floated about 200 yards downstream.

Sheriff deputies arrived about 8:22 PM. The TN highway patrol after 8:30 PM and rescue personnel arrived several minutes later. A total of 4 passenger cars and one tractor-trailer with 8 occupants had plunger into the river. All died of head injuries.

Two 2-lane bridges span the Hatchie River. Northbound traffic crossed the river over a 2-lane bridge designed in 1931. Southbound traffic crossed the river over a parallel 2-lane bridge designed in 1974, located 58 feet west of the northbound bridge. The average daily traffic for each bridge was 5,730 vehicles. The northbound bridge opened in 1936 and was 4,201 feet long. The bridge consisted of 143 spans supported by 2 concrete abutments, 117 concrete pile bents, 18 pile-supported concrete column bents and 7 pile-supported concrete piers. The superstructure was designed with 137 (28.5 foot long) simply supported spans across the flood plain and 5 (43-foot long) simply supported spans extending across the main channel and an 81.5 foot long pony truss center span. The spans consisted of 5 longitudinal reinforced concrete T-beam girders that were 14 inches wide and 21 to 22 inches tall. The girders were constructed of 2 layers of 1 to 1.25 inch square steel rebars. The girders supported a 24 foot wide, 8 to 10.5 inch thick reinforced concrete deck. On each side of the deck, a 33-inch tall concrete masonry bridge rail was attached to a 9 inch curb. The main channel concrete piers were 44.6 to 46.6 feet tall.

NTSB/HAR-84/03
Collapse of a Suspended Span of Interstate Route 95 Highway Bridge Over the Mianus River, Greenwich, Connecticut, June 28, 1983

At 1:30 am on June 28, 1983, a 100-foot suspended span between piers 20 and 21 of the eastbound traffic lanes of I-95 bridge over the Mianus River in Greenwich, CT collapsed and fell 70 feet into the river below. Two tractor-trailers and two automobiles plunged into the void. 3 occupants died and 3 received serious injuries. An inside hanger in the southeast corner of the span came off the inside end of the lower pin, shifting the entire weight of the southeast corner onto the outside hanger. The probable cause of the accident was the undetected lateral displacement of the hangers of the pin and hanger suspension assembly by corrosion induced forces due to deficiencies in the inspection program.

An automobile was in the median lane of the three-lane eastbound roadway. A tractor trailer was abreast in the center lane and another in the curb lane and slightly ahead. There was a sudden flash of light and the highway overhead lighting went off. At the same time the brake lights of the two trucks came on and the semitrailer began to change its alignment as though as it was starting to jacknife. The driver of the following car braked his vehicle hard and suddenly the 3 vehicles ahead disappeared from view. When the driver got out, he was 6 feet from the edge where a section of the bridge had fallen into the river 70 feet below.

The bridge is a deck bridge, 2,656 feet long and 70 feet above the river. Most of the bridge is above land. Distance between spans is 100 feet. Much discussion about the construction of the bridge is not repeated here. Pin and hanger construction, which corroded due to lack of maintenance. The bridge was designed in 1955. The maximum dead, live and impact loads at the southeast corner of the bridge was calculated to be 376,000 pounds. The highway was designed to carry a daily traffic volume of 30,800 vehicles, but in fact 81,000 passenger cars and 8,600 commercial vehicles used the bridge daily. None of the vehicles involved were overweight.

The accident rate for I-95 on the Mianus Bridge was 1.14 accidents per million vehicle miles.

NTSB-RAR-76-1
Burlington Northern Inc Monomethylamine Nitrate Explosion, Wenatchee, Washington, August 6, 1974

At 12:32 PM on August 6, 1974, a shipment of Monomethylamine Nitrate solution detonated during routine switching operations in the BN Apple Yard in Wenatchee, Washington. The explosion killed two persons, injured 113 and destroyed equipment and buildings. NTSB could not positively identify the cause of the explosion.

On July 29, about 10,000 gallons of PRM was shipped by DuPont, Biwabik, MN to DuPont, Wash. The tank car arrived, after several stops, in Wenatchee at 6:55 AM on August 6, 1974. The shipment was involved in switching operations when it began to spew smoke and fire then detonated.

Apple Yard lies on the west bank of the Columbia River, south of Wenatchee. The T was 82^{o}F. At the time there were nine cars adjacent to the car. The area surrounding the yard was residential.

Parts of the tank car were found one mile from the accident. Many cars were ignited and hundreds of acres of grassland burned. Most of the structural damage was within a radius of one mile, but broken glass was reported 3.5 mi east and 2.5 mi north. 71 cars and 4 containers were demolished. Size of the crater?

The cargo was PRM crystals in a water solution, to be used in a explosive product called TOVEX.. About 4000 pieces weighing 3,760 lbs or 19% of the tank shell were recovered.

NTSB/SIR-87/01
Collision Between a Tractor-Semitrailer Transporting Bombs and an Automobile Resulting in Fire and Explosions, Checotah, Oklahoma, August 4, 1985

About 12:30 AM on August 4, 1985, the drivers of two tractor-trailers departed the Explosives Transport Inc terminal in Oklahoma City, Oklahoma, heading east on I-40 for Southport, North Carolina. One truck was carrying 20 MK 84 general purpose bombs and the other 10 MK 84. The 2000 pound bombs had been loaded onto the flatbed semitrailers the previous day at the McAlester Army Ammunitions Plant and transported to Oklahoma City. The bombs were part of a total shipment of 350 bombs previously loaded onto 18 trailers on August 2 and 3.

The two trucks traveled east on I-40 for 130 mi. About 3:30 AM both trucks were in the right lane. The driver and passenger in a 1977 Fort LTD sedan also traveling east on I-40 was in the right lane. The driver had intended to exit I-40 at its intersection with US69, but passed the exit ramp. She slowed and then decided to proceed to the next ramp when she saw a truck approaching from behind. She expected the driver to pass in the left lane which he did. But the second truck struck the rear of her vehicle. The automobile rotated 180^{o} and traveled 164 feet, stopping near the guard rail. The tractor trailer stopped near the front of the auto.

The lead truckdriver saw flames in the rearview mirror and continued to travel east on I-40 calling for help on his radio. The lead truckdriver stopped at an exit further east and called the company dispatcher.

Immediately after the collision, a fire erupted and engulfed the rear and right side of the auto and the front of the tractor. The autodriver was pulled from her car and down an adjacent hill.

At 3:34 AM the Checotah Police Dept was informed of the accident. When the police officer approached the accident, flames were high above the wreckage. The fire dept approached the accident scene by old US 69 highway. A placard said class A explosives. About 3:45 AM the fire trucks were preparing to withdraw from the scene when an explosion occurred. Shortly after 4 AM a second explosion occurred. About 4:22 AM a 3rd explosion occurred. This explosion, the most violent, shook Muskogee, Oklahoma, 20 mi away. It made a crater 27 feet deep and 35 feet wide. About 4:30 AM the highway patrol called explosives ordnance disposal at Ft Sill. The bombs were filled with tritonal.

The Army Corps estimated that 371 residences within a radius of 6,200 feet were damaged; 22 homes needed major reconstruction and 11 homes needed to be rebuilt. The explosion also destroyed a fire truck, 2 eastbound lanes of I-40, the right shoulder of the highway. Approximately 3,382 tons (1,700 cubic yards) of material were used to fill the crater.

No shipping containers were used. Five pallets, 2 bombs to a pallet. The first two pallets were loaded side by side, 4 bombs across at the front end of the semi. Another four were loaded the same way directly behind. The fifth pallet was located in the center, directly behind.

Each MK84 bomb weighed 1,970 pounds and contained 945 pounds of tritonal explosive. About 99 inches long and 18 inches in diameter. Tritonal is a mixture of 80% TNT and 20% powdered aluminum.

According to tests by DOD, the cook-off time was 4 min; a thermal coating would have extended the cook-off time to nine minutes. Gasoline or diesel fuel contained in vehicle fuel tanks contain sufficient fuel to cause bombs to deflagrate. Deflagrating bombs may generate sufficient energy to detonate adjacent bombs.

Following the accident, DOD recommended a safe withdrawal distance of 3/4 mile (for a rail car, 1 mile). Blast overpressure at those distances was estimated to be about 0.3 psi for a fully-loaded tractor-trailer (and 0.33 psi for a fully loaded rail car). The threshhold required for glass breakage is 0.25 psi, for ear damage 2.4 psi and for lung damage 14.5

psi. The probability of a person being hit by fragmenting ammunition was less than 1 in a million at the 4000-ft range.

Other accidents involving explosives: Roseville, California, April 28, 1973 (18 RR boxcars of bombs) and Benson, Arizona, May 24, 1973 (12 RR boxcars of bombs). The Safety Board has also investigated two other munitions accidents: August 1, 1984 Navy torpedo overturned at the intersection of two major highways in Denver. Enough fuel spilled to cause an explosion, but the fire department put out the fire before an explosion.. And May 10, 1985, a tractor trailer carrying munitions struck a parked vehicle on I-85 near Bonnieville, KY resulting in a fiery accident. C-4 plastic explosives ignited and burned intensely, but did not explode. In addition, on June 4, 1971, an automobile collided with a tractor-trailer transporting non-military explosives near Macon, Georgia. Gasoline and diesel fuel leaked from the vehicle fuel tanks, a fire quickly engulfed both vehicles and the cargo exploded. Two firemen, a wrecker-operator and 2 bystanders were killed and 33 persons injured.

The front of the tractor trailer had penetrated 18 inches into the rear of the automobile and caused a 5-inch split in the nearly full automobile fuel tank. This engulfed the automobile an trailer in flames. The first of the three explosions occurred 15 minutes after the collision and was probably a deflagration with propulsion. The second occurred about 30 minutes after the collision and was similar. The third occurred about 52 minutes after the collision and was a partial or full detonation of several bombs.

NTSB-RAR-75-2
Southern Pacific Transportation Co. Freight Train 2nd BSM 22 Munitions Explosion, Benson, Arizona, May 24, 1973

At 4:30 PM on May 24, 1973, Southern Pacific Co.'s freight train, 2nd BSM 22, left Lordsburg, New Mexico, a stop enroute from San Antonio to San Francisco. Cars 35 through 46 contained MK 82, 500-lb bombs. A series of explosions occurred between 6:50 PM and 1:15 AM that destroyed 12 munitions boxcars. The probable cause was a fire inside car 38 originating from sparks off the brakeshoes which ignited the sodium nitrate impregnated floorboards.

At 6:43 PM on May 24, 1973, the train was descending a 1% grade at Dragoon, Arizona at about 45 mph. The train consisted of 5 locomotives, 106 cars and a caboose. An explosion occurred with car 38. The explosion did not interfere with the progress of the train and occurred without the knowledge of the train crew. The conductor in the caboose notices burning crossties and notified the engineer who began braking. The train was traveling at 30 mph at the time.

A second explosion occurred which blew 6 bombs and a portion of a 7th from car 38. When the conductor saw fire and black smoke, he placed the train brakes in emergency and jumped from the caboose. Reconstruction of the accident showed that a piece of flooring was exposed to a fire of 1500 ^{O}F for 25 minutes. The outside of the board burned about 5 minutes.

As car 98 passed the point of the original explosion, a low order explosion of one of the bombs that had been expelled from car 38 produced a small crater. The train separated between cars 35 and 34. Explosions of varying intensity continued until 1:15 AM on May 25 (7 hours later!).

The accident occurred in a sparsely populated region of Arizona; the nearest residence was 5 miles away.

The MK 82 bombs consisted of coated steel casing filled with tritonal, fuse wells and charging tubes for arming the bombs.

The major explosions produced a 115 foot by 93 foot crater, 25 feet deep and scorched the desert 1/4 mile in all directions. The force of three of the main explosions were recorded by Seismological Observatory in Tucson, Arizona as 1.6, 1.4 and 1.2 on the Richter scale. Several cars exploded at about the same time. About 500 of the 2600 bombs were recovered unexploded. Bombs were blown as far as 1 mile from the main crater area. Windows were shattered in a home 5 miles from the accident. Spacer cars between explosive cars would have been helpful.

The history of this division of the Southern Pacific RR indicates 237 car fires during a five-year period including 14 fires from overheated journals, 184 fires from brakeshoe sparks, 2 fires from friction, 5 from spontaneous combustion, 10 in fans of refrigeration units and 22 from other causes.

Above 180 to 185 ^{o}C, the decomposition rate and heat released from tritonal increase rapidly. In a confined space, this can escalate rapidly into a self-accelerating reaction, leading to a low order explosion. Unconfined tritonal burns, producing a dense black smoke.

NTSB/RAR-90/02
Derailment of Southern Pacific Transportation Company Freight Train on May 12, 1989 and Subsequent Rupture of Calnev Petroleum Pipeline on May 25, 1989, San Bernardino, California

About 7:36 AM on May 12, 1989, Southern Pacific Transportation Co freight train 1-MJLBP-111 consisting of a 4 unit locomotive on the head end of the train, 69 hopper cars loaded with trona and a 2 unit helper locomotive on the rear of the train derailed at milepost 486.8 in San Bernardino, California. The entire train was destroyed. Seven homes were totally destroyed and 4 were extensively damaged. 2 crew members died and 3 were injured. Two residents were killed and one injured. Homes in the surrounding area were evacuated because of concern the adjacent 14 inch Calnev pipeline carrying gasoline and under the wreckage would rupture. Residents returned to their homes 24 hours after the derailment.

About 8:05 AM on May 25, 1989, 13 days after the train derailment, the pipeline ruptured at the site of the derailment and ignited. 2 residents were killed, 3 received serious injuries and 16 reported minor injuries. Eleven homes were destroyed and 3 received smoke damage. 21 motor vehicles were destroyed. Residents within a four block area were evacuated.

The probable cause of the train derailment was the failure to communicate the status of the dynamic brakes and Southern Pacific's rule that provided inadequate direction to the head end engineer on the allowable speed and brake pipe reduction down the 2.2% grade. Inadequate inspection of the pipeline following derailment that failed to detect severity of the damage due to earth-moving equipment.

Lake Minerals Corporation leased 69 100-ton open-top hopper cars to transport trona from Rosamond, California to the Port of Los Angeles. The route is shown in the Figure.

Figure. Mojave Subdivision of Southern Pacific. Derailment site is located near San Bernardino.

The train was assembled in 3 pieces since the rail facility at Rosamond would not accommodate the entire train. The yard clerks at Fleta estimated 50 tons (32 cars), 75 tons (15 cars) and 60 tons (22 cars), but in fact each car contained 100 tons each. The bill of lading listed 60 tons each, the figure used in the SF dispatcher's office. That is, the train dispatcher was not employing the correct weight of the train.

At 5 PM on May 11, 1989, the chief train dispatcher on duty at Los Angeles telephoned a yard clerk at Mojave and informed him of his plans to operate a train of 69 cars from Fleta to West Colton. The crew picked up a clearance form, train list and tonnage profile. The dispatcher arranged 3 locomotive units based on the weight of the train. Helper locomotive arranged to meet train at Oban and assist the train up the ascending grade to Hiland and through the Cajon Pass. The asst dispatcher believed the tonnage of Extra 7551 East was 8,900 tons.

The crew departed Mojave yard at 12:15 AM en route to Fleta with 4 locomotives. After waiting for the track to clear finally left Mojava again at 3:35 AM.

At 1:30 AM on May 12 the helper unit (2 locomotives) arrived at West Colton. At 5:06 AM the dispatcher instructed the helper engineer to couple with the rear of Extra 7551 East. The train then departed the siding at Oban and went to Hiland without unusual events. The train crested the hill at Hiland at about 25 mph. One of the helper units had inoperative brakes. The speed of the train increased to 30 mph. Braking was increased, but the train was traveling at 31 mph and increasing. Moved to full service braking, but did not slow. Without informing the front end, the helper engineer placed the brakes in emergency. The front end placed their brakes in emergency. The speed of the train continued to increase At 7:33:48 the conductor contacted the asst general yard master at West Colton yard. The helper engineer braced himself, with radio at hand, calling out speeds when it hit 90.

As Extra7551 East approached MP 486.6 and entered a 4-degree right hand curve, the entire train derailed to the outside of the curve, many of the cars crashing into a neighborhood of houses adjacent to the tracks at 7:37:55 AM. The fire department arrived at 7:55 AM. 11 houses had been impacted. Police units began arriving at 7:48.

Calnev stopped pumping gasoline through the 14 inch pipeline from the Colton terminal, 6 1/2 mi distant, at 8:30 AM. The pipeline was under a portion of the wreckage.

Locomotive had come to rest over the pipeline. Depth of the pipeline at that point was 7 to 8 feet. Cranes would pick up cars and swing them around to a breach constructed in the levee. Front-end loaders carried cars over through the breech to the west side of the track. Equipment continually moved over the submerged pipeline. Two cranes and a front end loader were used to lift the locomotives. The cranes moved over the pipeline at that point.

Calnev did not see any metal which had entered the ground. Brought in a backhoe to excavate the pipeline at the breech road. No damage to pipe found. Pressure in the pipeline remained constant. Removal of the trona continued through May 19, 1989. Still 2 to 3 feet of cover.

Following May 16, the pipeline pressure was increased to 1,667 psig.

At 8:05 AM, low suction pressure and low discharge pressure alarms were sounded and the three 1000 hp pumps were shut down by the computer. The attendant attempted to restart the pipeline several times but was unsuccessful. Then the San Bernardino County Communication Center called to ask about a fire. A resident reported that between 7:45 AM and 8 AM, a light colored rain was falling, than an explosion blew in her windows and the entire house was on fire. Another resident said that a train went by about 8 AM, followed by a rumble and an explosion. The fire department arrived about 8:13 AM. The fire burned out about 3:30 PM on May 25.

At the rupture location, four pieces of railroad debris -- a brake arm, an 8 inch section of I-beam, a piece of metal cowling from a locomotive and a short section of rail -- were found. The brake arm and the rail section were 2 to 3 feet in length. The brake arm was found 8 inches above the pipeline and other parts within 2 feet.

After repair and replacement of 600 feet of pipeline, the pipeline was refilled. More than 9,400 barrels were required to refill the pipeline. A mile of the pipeline holds 917.69 barrels of product. Apparently the pipe had been dented - 27 inches - producing a bulge on the inside surface the pipe and wall thinning.

Total injured: 6 serious, 23 minor. Total killed: 6

The pipeline, between Colton and Las Vegas, was constructed during 1969 and 1970. The pipe had a wall thickness of 0.312 inches, a yield strength of 52,000 psi and a tensile strength of 66,000 psi. The track itself was laid in 1967. In 69 and 70, no houses were yet located on Duffy St where the derailment occurred. Intensive construction took place 1970 through 1972.

A similar accident occurred June 27, 1989 in Las Vegas when a locomotive, used to switch the order of railroad cars at a Union Pacific Railroad yard overturned on top of two Calnev pipelines. About 8:30 AM, leading 9 cars and trailing 12 cars derailed. A pipeline on one side contained jet fuel and on the other gasoline. Both were buried 4 to 5 feet below ground.

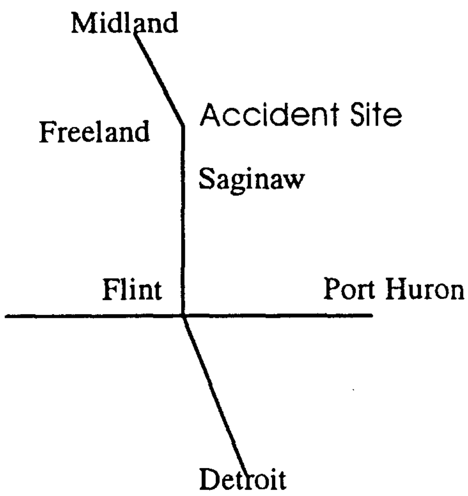
Santa Fe Pipeline Company (formerly Southern Pacific Pipelines Company) advised that 55% of its 3,300 mile pipeline was installed along railroad rights of way; between 1966 and 1989, 121 train derailments had occurred over pipeline.

NTSB/RAR-91/04
Derailment of CSX Transportation Inc Freight Train and Hazardous Materials Release Near Freeland, Michigan on July 22, 1989

About 11:20 am July 22, 1989 CSX Transportation Inc freight train R-331-22 derailed near Freeland, Michigan. The train consisted of 2 locomotives, 17 loaded cars, 15 empty cars and an unoccupied caboose. Of the 14 derailed cars, 6 were tanks cars. About 1000 residents were evacuated for 7 days.

The probable cause of the accident was inadequate car inspection by CSX and ATSF that resulted in wheel lift and the derailment of ATSF 90005. Large trimethylchlorosilane fire.

Crew reported for duty at Port Huron, Michigan at 5 AM July 22, 1989 and departed without incident for Midland, Michigan at 5:45 AM. At Flint the crew set out 14 cars and picked up 23 including an excess dimensional load and 11 cars of hazardous materials.



Route of freight train R-331-22.

The train departed Flint at 9:45 AM and proceeded without incident until Freeland, Michigan, about 11:20 AM. At that time, the train crew felt a slight lurch followed almost immediately by the train going into emergency. When they looked back, they saw cars derailing amid a large fireball and black smoke. The train was traveling about 37 mph. Emergency response personnel arrived about 11:30 AM. About 1000 residents were evacuated within a 1/2 mile radius of the accident site. Hazardous materials burned for 6 days. The evacuation order was lifted at 8:56 PM on July 29.

The entire crew was rested. The inspections of the train were standard. Its gross weight was 3,123 tons (276 tons engine weight and 2,847 trailing weight).

ATSF 90005 was a heavy capacity depressed center flat car, the second car in the train with empty idler cars before and after. The eight axle car had a light weight of 92 tons and a load limit of 170 tons. Total allowable weight on rail was 263 tons. But apparently the weight was too great and the wheels were rubbing on the underside carriage.

Of the 15 cars that contained hazardous materials, 7 derailed. They included cars loaded with styrene monomer, acrylonitrile, acrylic acid, petroleum naptha and a mixture of chlorosilanes, including trimethylchlorosilane. Styrene and acrylic acid are flammable, corrosive and can polymerize, releasing heat in the process. Acrylonitrile and trimethylchlorosilane are flammable liquids, corrosive and difficult to extinguish. The latter forms hydrochloric acid in the presence of water.

Class 3 track required weekly inspections, with at least 3 calendar days between inspections or before use if the track is used less than once a week. A track geometry car was last operated on June 22 and a deviation was corrected on June 26. The train was operating below the speed of 40 mph allowed. The heat generator on the flat car that overturned was en route to Midland from Chanute, Kansas to convert the Midland plant to a gas-fired plant.

Apparently the load was not centered. Ballast was not added to the car to correct the center of gravity because this would exceed the maximum limit. 3 modules had been transported without incident before the accident. This same car had derailed 3 times before the accident. Car had derailed March 31, 1989 in Flint without incident on a 2 degree curve. About 1 PM on April 7, ATSF 90005 derailed in the yard at 1 mph.

The command post was moved three times during the first 7 hours after the accident as the wind changed. Hazardous material response teams from Dow Chemical, Dow Corning and Rohm and Haas were enroute within 2 hours after the derailment. On July 23, all parties decided to allow the burning to proceed. On July 25, with the trimethylchlorosilane still burning, the fire chief tried sodium bicarbonate. A reaction occurred that created hydrogen gas that ignited. Tried increased air to accelerate burning. Still burning on July 28. Tank cars emptied and evacuation lifted at 8:56 pm on July 29. One car flexed when lifted.

The evidence indicates the initial derailment occurred when a wheel on ATSF 90005 lifted. Harmonic roll involved, transferring weight from one wheel to another. Meanwhile lateral forces took wheel off track. The high cg contributed to roll.

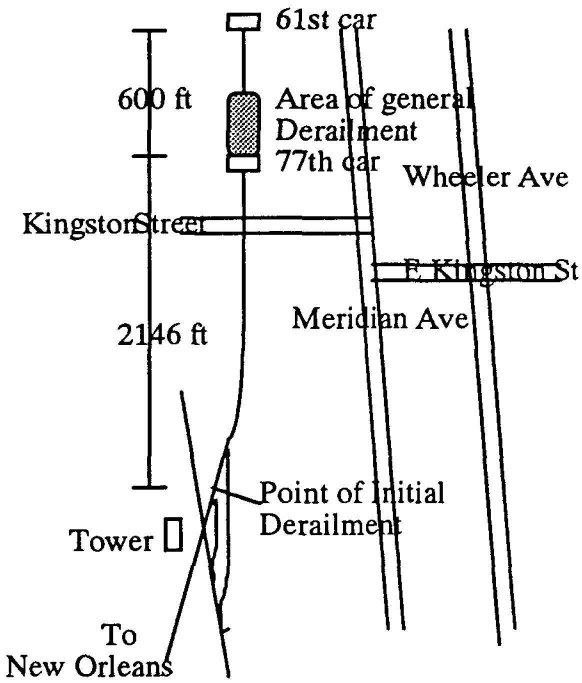
Southern Railway Company Train 154 Derailment with Fire and Explosion, January 25, 1969

Southern Railway Company train 154 was wrecked at Laurel, Mississippi, about 145 mi north of New Orleans, on January 25, 1969 at about 4:15 am when 15 tank cars of liquefied petroleum gas derailed. The train, with four locomotives, 139 cars and caboose was moving northward at 30 mph when the west wheel on the lead truck of the 62nd car broke. The car derailed about 256 feet north; the entire train behind the 62nd car derailed 2,146 feet further north.

For about 40 minutes after the derailment there were continued explosions; pieces of tank cars ranging in size from 3/4 of a tank car to small parts were hurled up to 1,600 feet from the wreck, igniting dwellings and commercial buildings. At least 3 tanks rocket-propelled over long distances and started fires where they came to rest. Residents were evacuated from an area about 10 blocks square. A total of 54 residences were substantially destroyed and over 1350 residences suffered some damage. On January 26 residents returned and slow speed service was restored at 5:30 PM.

The speed at the time of the accident was between 28 and 35 mph. Tanks cars 30,000 gallons. The weather was clear with a brisk northwest wind and $T = 35^oF$.

The train left the Oliver Yard, New Orleans at 12:10 am with 76 loads, 37 empties and a caboose and four locomotives. The crew of train 154 picked up 26 tank cars (30,000 gallons each) of LP gas at Dragon, MS and put them in the train behind the 60th car. Dragon is 25 mi south of Laurel.



From Dragon, the train had a total tonnage of 10,486 tons (102 loads, 37 empties, caboose), arriving at Laurel at 4:15 am. Speed was about 28 mph. October 1968, the GM&O crossing was completely reballasted and the crossing surfaced. Immediately after the 1st of 26 tank cars (the 61st car) passed the crossing, the operator heard a loud noise and saw sparks and fire around the front truck of the 62nd car. He went to the tower to notify the dispatcher at Hattiesburg to stop train 154, but before he could do this the derailment occurred. The cause of the derailment was a broken wheel. Substantial tread worn hollow condition. The mating wheel derailed about 256 feet further.

14 of the derailed cars, about 850 feet in length, were piled into a space of about 400 feet in length. The first 61 cars remained on track. The rear 63 cars remained on track, with the 76th car stopping about 20 feet from the derailed cars. Large mushrooms of flaming propane shot hundreds of feet into the air. 19 pieces of tanks were hurled off the right of way. One piece of tank car was hurled into a pumphouse of a city well and cut an 8 inch water main, reducing the pressure. The fires in the residential area were under control by 11 am, 6 1/2 hours after the wreck occurred.

A 37 foot section was propelled 1000 feet in the air from the wreck, bouncing several times and coming to rest 1600 feet from the wreck center. A 37 foot section was propelled 800 feet from the wreck, striking the peak of a roof, then bounced to about 1100 feet from the wreck.

The Police Chief issued instructions to seal off the area and evacuate residents at 4:20 AM. There was no telephone and electric power in parts of the city. No explosions after 5 AM. A damaged tank car was exploded. Residents returned at 10:30 AM January 26.

Broken windows as far south as 3 mi from Laurel. 2 fatalities and 33 persons hospitalized.

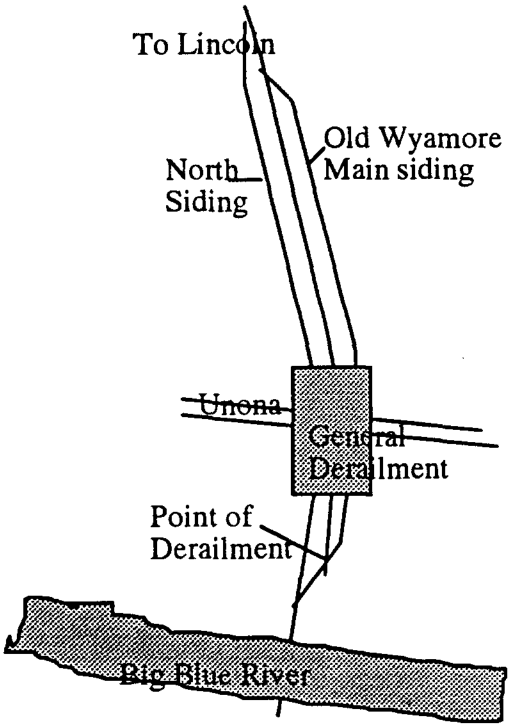
NTSB/RAR-71/2

Chicago, Burlington and Quincy Railroad Company Train 64 and 824, Derailment and Collision with Tank Car Explosion, Crete, Nebraska, February 18, 1969

At about 6:30 AM on February 18, 1969, Chicago, Burlington and Quincy Railroad Company Train 64 derailed the 72nd to 90th cars at a turnout located on a 2^{o} curve as the train was entering Crete, Nebraska, at a speed of 52 mph. The derailed cars struck standing cars on a siding south of the main track and the cars of train 824 standing on a track north of the main track. A tank car in 824 was completely fractured by the impact and released 29,200 gallons of anhydrous ammonia. A gas cloud was released and blanketed the area for quite some time due to weather conditions. 3 trespassers on train 64 were killed and 6 people were killed and 53 injured as a result of the ammonia cloud.

The derailment was due to movement of the rail caused by lateral forces. The cause of the complete failure of the tank car was due to its being struck by the coupler of another car and the brittleness of the tank car steel at $4^{o}F$.

The accident occurred at Crete, 20.1 miles west of Lincoln on CB&Q's Lincoln Division which extends from Gaines to Lincoln, 98.4 mi. Other tracks: a single track branch line, the Wymore Branch, connects with the main track at a point 4016 ft west of Crete. At Crete a siding, 3996 ft in length, known as Old Wymore Main, parallels the main track. A siding 4,703 feet also parallels the main track on the north. A bridge over the Blue River is 382 ft in length. West of Crete on the main track, there is a 2^{o} curve to the south for 2106 ft and then straight for 1175 ft over the bridge.



About 2 AM, February 18, train 824, consisting of one locomotive and 49 cars entered the main track from the Wymore Branch and then moved into the north siding. The train was stopped on the siding with 3 cars of anhydrous ammonia in the vicinity of the Unona Ave crossing.

Train No. 64, operating as Extra 624 East, consisting of 7 locomotives, 92 cars and 3 cabooses, weighing 6,364 tons, left Gaines at 4:55 AM. The train reached about 60 mph about 4.5 mi west of Crete. The throttle was moved to the idle position and the train slowed to 47 mph, but its speed increased on a 0.57% descending grade. Brake applied about 2 mi west of Blue River. Was going 52 mph over the bridge.

Temperature inversion at the time, that is, the lower air was cooler than the upper air.

At 6:30 am, the emergency brakes went on; the engineer released the brakes so that the rear of the train would not run into the front. The air hose had parted between the 14th and 15th cars. A piece of rail was wedged under the car on the airbrake valve of the 28th car. The train had parted on the 71st car. The conductor and flagman saw a dense cloud forming, smelled ammonia and ran westward.

Some irregularities found in track condition. The 72nd to 75th cars derailed southward and struck a boxcar and came to rest about 700 ft east of the initial derailment. The 76th and following cars were diverted northward and struck the standing cars of No. 824, including the 3 tank cars loaded with anhydrous ammonia. The 38th and 40th cars containing ammonia were turned on side, east and west of Unona Ave. The tank of the 39th car shattered after being struck by derailed cars, the tank divided into two sections.

The top portion, about 16 ft in length, was propelled 200 ft over Highway 33 and landed in the front yard of a residence. The bottom portion of the head, with part of the center sill attached, was hurled northward about 140 feet where it landed along Unona Ave.

Anhydrous ammonia is a liquid that boils at -28^{o}F at atmospheric pressure. One part liquid volume becomes 877 parts gas volume. Because of the inversion and lack of wind, the gas cloud remained. 5 people were killed immediately and 28 people injured seriously. Another person died subsequently. Between 200 and 300 people were evacuated with difficulty. Extra masks were found at the local grain mill and National Guard armory. Evacuees returned home at 11 am February 20th.

The three tank cars of anhydrous ammonia had been loaded by the Philips Petroleum Corp in Hoag, Nebraska, 24.6 mi south of Crete. The car contained 159,660 lb or 29,188 gallons of ammonia. The car could hold 33,639 gallons. The shell was constructed of 5/8 inch steel plate. The coupler of the 87th car struck the tank head and caused the primary fracture. The metal was brittle at the low temperatures.

Apparently the brakes were applied while the rear of the train was still descending the grade causing compressive forces. The 7 locomotives weighed 2,075,000 pounds. A 22,000 pound force, 0.01g, would hold the train at constant speed. About 25 times more forceful braking would be possible before wheels of the locomotive began to slide.

NTSB-RAR-72-1

Penn Central Transportation Co Freight Train Derailment, Passenger Train Collision with Hazardous Material Car, Sound View, Connecticut, October 8, 1970

8 cars of the westbound freight train Advance CB-1 derailed at Sound View, CT at 8:50 PM on October 8, 1970. This was immediately prior to the arrival of eastbound passenger train No. 174. This is a double track line. The entire passenger train was derailed and continued through flames. The derailment was due to the breakage of a truck side frame of a car on the freight train.

The maximum allowable speed of the passenger train was 70 mph and 50 mph for the freight train. The passenger train was going 60 mph at the time. Moments after passing the lead units of CB-1, No 174 sideswiped a derailed car. Much of the sheet metal destroyed on passenger locomotive.

NTSB-RAR-72-2

Derailment of Toledo, Peoria and Western Railroad Company Train No. 20 with Resultant Fire and Tank Car Ruptures, Crescent City, Illinois, June 21, 1970

Train No. 20, an eastbound freight train of the Toledo, Peoria and Western Railroad Company consisting of a 4 unit locomotive and 109 cars derailed the 20th to 34th car at the est switch of the siding in Crescent City, IL at 6:30 AM on June 21, 1970. Nine of the 15 derailed cars contained liquefied petroleum gas. This ignited. A series of explosions began 1 hr following the derailment and injured 66 persons and destroyed several buildings. The probable cause of the derailment was the breaking of the L-4 journal of the 20th car due to excessive overheating which allowed the truck side to drop to the track and derail the leading wheels of the car. The speed of the train allowed jumbling of the cars. The fact that the tank cars were placed next to each other involved the unpunctured cars in the fire and subsequent explosions.

The track was straight and grade level. Crescent City is built on both sides of the track. The allowable speed limit was 49 mph. As it moved through Gilman, one motorist stopped on Rte 45 observed smoke from a journal box. Crescent City is 7.2 mi east of Gilman. The train was going 43 mph just west of Crescent City. The force of the derailment propelled the 27th car over the derailed cars ahead. It came to rest with its west end resting on the derailed cars, 15 ft in the air. As it was hurtling through the air, its coupler struck the tank of the 26th car, puncturing the head end. Flames reached several hundred ft in the air.

The fire dept was immediately notified and began spreading water on the derailed cars. The fire seemed to be confined to the center of the derailed cars. Seeing the propane cars, a state trooper at the scene informed the fire crew that it should back to a safer distance to fight the fire. Some pressure relief valves began to release more propane, increasing the intensity of the fire. A wooden pole carrying electric power to Crescent City was sheared in the accident. At 6:45 AM, an employee of the power company de-energized the lines. 12,000 and 2,400 volt lines, the main power sources to Crescent City, were deenergized at 6:45 am. A 69,000 volt line was de-energized at 7:05 AM, shutting the water pumps for the town's water supply. The firemen backed off at that point and the fire increased in intensity.

The 27th car, partly in the air, was heated by the fire below and exploded, causing a crater in the ground and rocketing about 600 ft eastward. The west end of the car was hurled in the southwesterly direction for a distance of 300 ft, collapsing the roof of a service station. Fire companies from 32 surrounding towns dispatched 53 pieces of equipment and 234 firemen, including water trucks. There was no central communication for this firefighting effort.

At about 9:40 AM, the 28th car ruptured. The south end of the car was hurled 200 feet southward across Main Street and entered a brick apartment building. The north end of the car was hurled through the air in a northwesterly direction over the roofs of several houses and landed in an open field and finally stopped 1600 ft from the derailment.

About 5 minutes later, at 9:45 AM the 30th car in the train ruptured. The north end of the car was propelled 600 ft, passing through 2 bldgs and coming to rest within a third.

At about 10:55 AM, the 32nd car of the train and the following car ruptured almost simultaneously. It struck and punctured the 34th car which ignited. The other end of the 33rd car was hurled through the air. It struck the 34th car, ricocheted and struck the protective housing of the 35th car. The housing and the valves of the 35th car broke off, which permitted propane to escape and ignite. The 34th car burned until all the propane was consumed, until 9 PM June 22, for a total of 38 1/2 hrs and the 35th car until about 2:30 PM on June 23, a total of 56 hrs. Residents returned home at 2 PM on June 22.

66 persons were injured; no fatalities. 16 businesses destroyed and 7 damaged; 25 residences were destroyed.

The record on hot boxes (ratio of car miles to freight cars set out due to hot boxes), as collected by the AAR:
from 1954 to 1960, average yearly mileage fluctuated between 231,813 and 314,500
in 1961 the mileage per hot journal set off increased until reaching a high in 1967 of 1,834,922. Despite this improvement, the number of accidents caused by hot boxes has not been reduced similarly. In 1955, 595 accidents caused by the failure of overheated journals and in 1969, 495. This might be due to the fact that rail companies are now less attentive to the problem since it is occurring less frequently, and less employees are located along tracks.

Generally, it is not best policy to extinguish a propane fire because an unignited cloud could ignite downwind. It would be better to keep the surrounding tank cars cool while allowing the released gas to remain lit.

Tank cars erupted after the fire had softened the metal. The cars bulged, thinning the metal further and then exploded.

NTSB-RAR-76-8
Derailment of Tank Cars with Subsequent Fire and Explosion on Chicago, Rock Island and Pacific Railroad Company Near Des Moines, Iowa, September 1, 1975

At 4 PM on September 1, 1975, 17 cars of a Chicago, Rock Island and Pacific Railroad Company train derailed on the main line near Des Moines, Iowa. The train was descending a 1% grade on a 1^{o} curve. Eleven of the derailed cars contained LPG.

On Sept 1 at 10:30 AM, freight train no. 81A31 departed Manly, Iowa bound for Des Moines. When it departed Iowa Falls, it consisted of 2 locomotives, 43 loaded cars, 18 empty cars and a caboose. Cars 24 through 34 were LPG cars. The train was descending a 1% grade. As the train accelerated to 25 mph, the engineer made a 6 lb brake pipe reduction. About 4 PM, either the rear truck of car 26 or the lead of car 27 traversed the frog of a left-hand turnout and derailed towards the east. The coupler of car 28 penetrated the trailing end of car 29. The first of several explosions occurred about 9 minutes after the initial derailment. Parts of 3 tanks rocketed; 3 exploded and formed flat sheets and others burned.

Local firefighter responded immediately but before setting up a 2nd explosion occurred and they decided not to fight the fire. After retreating another car exploded and cast fragments into a nearby storage facility of LPG.

About 15 minutes after the train derailed, the Iowa State Fire Marshall observed the area from a helicopter and ordered that it be evacuated. The area was declared safe for reentry on September 5, 4 days after the accident. An estimated 300,000 gallons of LPG were consumed in the fire.

Class 3 track; 30 mph speed restriction. The running gear of the 1st 3 cars showed no mechanical deficiencies.

NTSB-RAR-78-8
St Louis Southwestern Railway Company Freight Train Derailment and Rupture of Vinyl Chloride Tank Car, Lewisville, Arkansas, March 29, 1978

About 12:10 AM on March 29, 1978, 4 locomotive units and 43 cars of St Louis Southwestern Railway Company freight train SRASK derailed when they entered an 8° curve in the Y track at Lewisville, Arkansas. The body of the 13th car struck and ruptured the tank head of the 12th car releasing vinyl chloride into the air which ignited. Bldgs within 1500 ft of the ruptured car were damaged and 1700 residents evacuated.

The probable cause was the failure of the engineer to slow train SRASK for the 10 mph speed restriction. Lateral forces pushed the locomotives wheels off the high rail.

The train consisted of 4 locomotives and 116 cars. It departed Shreveport, Louisiana for Pine Bluff, Arkansas at 9:50 PM. Brake and hot box checks were made along the way. As SRASK approached the milepost sign indicating 1 3/4 mi to Lewisville Y, the train was moving at 35 mph and brakes were applied, and again 3/5 mi and 1/2 mi. But simultaneously the head brakeman applied the emergency brakes. The train was going too fast and as it passed the Y and the 8° curve it tipped over. The train's speed in entering the Y was 35 mph. The following 16 cars derailed. The body of the 13th car struck and ruptured the tank head of the 12th car releasing vinyl chloride into the air which ignited. The fire engulfed the locomotive and the first 16 cars, a fireball that extended 1000 ft. The intensity of the fire decreased over 24 hours. Residents were allowed to return the next day.

The 61 year old engineer's health was good. He had been operating locomotives for 21 years and had made 400 trips in this area. The 47 year old head brakeman had been a brakeman for 10 years.

The 10th and 11th, 12th through 15th, 28th and 29th, 35th through 41st and 54th through 57th cars were loaded with butadiene, vinyl chloride, tetrahydrofuran, propylene oxide and butadiene, respectively.

A fire started at 12:10 AM.

Lateral forces caused the rail to move outward. The emergency brake application would have increased the lateral forces at that point.

NTSB-RAR-79-1

Derailment of Louisville & Nashville Railroad Company's Train No. 584 and Subsequent Rupture of Tank Car Containing Liquefied Petroleum Gas, Waverly, Tennessee, February 22, 1978

About 10:25 PM on February 22, 1978, 23 cars of a Louisville & Nashville Railroad Company's Train No. 584 derailed at a facing point switch in Waverly, Tenn. At 2:53 PM on February 24, a derailed tank car containing LPG ruptured, igniting with explosive force. As a result 16 persons died and 43 were injured. The cause was a crack caused by the derailment. The car exploded during movement of the car for transfer of product. The derailment was due to a broken wheel on the 17th car.

About 14 mi north of Colesburg, train no. 584 received a "no defect" indication from a hot journal detection device. At 10:25 AM, while operating in compliance with the 35 mph restriction through the City of Waverly, the train's brakes went into emergency. The train had separated when the 17th through 39th car derailed. Two LPG tank cars were part of the derailment. No leakage. Mgmt decided to move the tank cars to a position alongside the track structure where the lading could be transferred into highway tan trucks. Cable slings were placed around the north end of the tank car and using the opposite end as a pivot, the car was moved about 12 ft eastward and wooden crossties were placed under the north end. The other tank car was similarly moved and the relocations were completed by 2:15 PM. Still no leakage.

L&N's wrecking crew continued to remove the derailed cars and the main track was opened to rail traffic 8 PM, February 23.

A semitrailer truck arrived at Waverly about 1 PM on February 24. The transfer had not yet started when, about 2:53 PM, the tank car ruptured and released LPG which ignited downwind. 16 persons died and 43 were injured as a result. 18 bldgs and 26 motor vehicles were destroyed. The Waverly fire equipment was destroyed in the fire, but equipment from neighboring communities was brought in. By 3:45 PM, deluge guns poured water onto the tank cars. By 5 PM all fires in the vicinity were extinguished.

About 1000 psig is the bursting pressure of the tank. The rupture occurred at a pressure of 300 psig, due to the weakened condition.

The high carbon wheel wears better, but if wheels heats because of dragging or sticking brakes, the wheel tends to crack and break. The tank car was constructed of 25/32 inch steel and held 30,149 gallons.

NTSB-RAR-76-10

Head-On Collision of Two Penn Central Transportation Company Freight Trains Near Pettisville, Ohio, February 4, 1976

About 11:52 PM on February 4, 1976, Penn Central Transporation Company freight train NY-12 collided head-on with freight train BM-7 near Pettisville, Ohio. The 3 locomotives and 21 cars of NY-12 and the 4 locomotives and 4 cars of BM-7 were derailed. The head locomotive unit of each train was destroyed and the two crew members in each unit were killed. The probable cause of the accident was the failure of the engineer of NY-12 to stop the train west of the signal.

Freight train NY-12 was headed eastbound from Elkhart, Indiana to Toledo, Ohio at 9:15 PM. The train consisted of 3 locomotives and 73 cars. Penn Central freight train BM-7 originated in Selkirk, NY. The train consisted of 4 locomotives and 113 cars when it departed Cleveland. BM-7 stopped on the main track at Toledo to change crew after which it departed westward on track 2 for Elkhart at 10:30 PM.

About 11:43 PM, BM-7 was moving west on track 2 in the vicinity of CP320 and NY-12 was moving east in the vicinity of CP329. The train dispatcher planned to have train BM-7 cross over from track 2 to track 1 at CP327 so that NY-12 could proceed on track 2. When BM-7 entered the block between CP320 and CP327, it caused signal 327E, which was governing the eastbound movement of NY-12 to display a "stop." As BM-27 moved towards CP327, the switches were lined and the signals actuated for BM-7 to cross over to track 1. But NY-12 did not stop and continued its speed of 35 mph.

When the engineer of BM-7 saw NY-12 approaching on the same track, he called over the radio, but received no response. The two trains collided about 11:52, 1 mi east of CP327.

The double main track is straight for more than 15 mi and visibility was about 15 mi.

The maximum authorized speeds for freight trains on this track is 50 mph. All trains had radios. It appeared all signals and switches were acting properly. All crew had sufficient rest. Alcohol tests could not be run because of the state of the bodies, i.e., no blood.

NTSB-RAR-76-4
Collision of Reading Company Commuter Train and Tractor-Semitrailer Near Yardley, Pennsylvania, June 5, 1976

About 11:06 PM on June 5, 1975, a Reading Company commuter train struck a tractor-semitrailer at a grade crossing near Yardley, Pennsylvania. The truck was transporting 3 coils of steel, two of which penetrated the first commuter car. The three occupants of the lead car were killed. The truckdriver was uninjured. The semitrailer was torn from the tractor and the lead commuter car was damaged extensively.

The automatic grade crossing signal system was functioning.

Commuter train 571 was traveling westbound from Trenton, New Jersey to Philadelphia. The train consisted of two cars and traveling at 60 mph toward the Stony Hill Road grade crossing. The engineer's view was obstructed by the curvature of the track and the adverse weather conditions, namely a thunderstorm. As the train was approaching the grade crossing at 11:05, the truck was approaching the crossing from the south. Two of the coils weighed 8 tons and one coil weighed 5 tons. The truck driver's view was obstructed. The truck was traveling at 15 mph. The truckdriver said he neither saw the train or the crossing signals so he proceeded. His first indication were the train headlights. He attempted to accelerate, but did not clear the track.

The lead cars buffer sill struck the right rear of the trailer. The coupler penetrated the trailers main frame rail 8 feet from the rear of the trailer, about 3 ft above ground level. The coils of steel were torn from the chains and the coils entered the commuter car. The center vestibule compartment had been dislodged rearward 26 ft, to the vicinity of the 23rd row of seats by the 8 ton coil. The train stopped 1155 ft west of the crossing.

All the warning signals are activated by westbound trains when they reach a point 5170 ft east of the crossing. At 60 mph, train 571 would have provided about 1 minute of warning to drivers approaching the crossing.

Stony Hill Road is a 20 foot wide paved two lane road. The posted legal speed is 45 mph. The signals are visible from the south about 500 ft from the crossing. The average daily traffic was 2648 vehicles and 38 trains. From Jan 1, 1974 through June 6, 1976, there were four accidents including this one.

The train cars were designed to withstand an 800,000 lb static compression end load at the centerline. Each car weighed 63.5 tons. The trailer had a sliding axle suspension. The trailer height (top of bed) was 54 inches. Each steel coil was on a pallet 7 inches high. Empty weight of the trailer was 5.6 tons. The diameter of the steel coils was 4 ft (8 ton) and 3 ft (5 ton).

The 8 ton coil struck the left front collision post of the lead car 38 inches above the car floor, shearing the post at the base. The coil traveled through the car and came to rest 66ft from the front of the car.

Highway Accidents

NTSB-HAR-72-5
Automobile-Truck Collision Followed by Fire and Explosion of Dynamite Cargo on US Highway 78 Near Waco, Georgia on June 4, 1971

At 8 PM on June 4, 1971, a 1961 Volkswagen sedan traveling west on US Highway 78 crossed over the centerline of the two-lane highway and collided head-on with an eastbound tractor-semitrailer transporting 12.7 tons of explosives. Both vehicles were traveling 40 mph before impact. Fire broke out immediately in front of the trailer. Firemen arrived shortly thereafter and tried to put out the fire, but the cargo detonated 10 to 15 minutes after the collision.

The automobile driver died in the collision. Two firemen, a wrecker driver and two bystanders died as a result of the explosion, 33 people were injured.

Contributing causes to the fatalities were the decision of the firemen to fight the fire, the failure to notify emergency personnel of the hazard and inquisitive nature of bystanders.

The collision occurred in a residential area on the outskirts of Waco. The truck veered to the shoulder to avoid the accident, jammed on the brakes and struck the center of the automobile's bumper. It traveled 130 feet further. The impact pushed the automobile backwards and it came to rest about 40 feet west of the truck. There was a solid mass of flames alongside the entire left side of the trailer. Small bushes were also burning. Strong odor of gasoline. The truckdriver exited the passenger side and stopped traffic in both directions. The truckdriver frantically tried to warn bystanders of the contents of the truck.

The fire dept arrived about 10 minutes after the collision and began to fight the blaze. The detonation disintegrated the truck. The engine block was blown 95 ft northeast of the accident and the suspension an additional 45 feet. The rest of the truck, shrapnel, was blown several hundred ft in all directions. Other vehicles within a radius of 400 ft were severely damaged by the shrapnel. Windows were broken as far as 1 mi from the accident scene. Drainage ditches on both sides of the highway. The explosion created a crater centered near the middle of the westbound lane, 40 to 50 ft wide, 50 to 60 ft long and about 20 ft deep.

The bottom of the diesel tanks was about 10 inches above the road. The trailer weighed 5 tons and was 12.5 ft high. The VW weighed 0.8 tons.

The truck carried 50 cases of Gelamite #1 (18% nitroglycerin), 100 cases of Hercol 2 (8% nitro), 208 cases of Flogel, 13 cases of Titan Boosters (detonating agent), 2 cases of Reinforced Primacord (detonating fuse) and 50 cases of 60% extra Gelatin (30% nitro). The latter is the most explosive. All manufactured by Hercules. No regulations for loading configuration. No blocking or dividers. No unused space in the trailer. Warning placards were installed on four side of the trailer. No regulations for clearance of fuel tanks above the highway.

Persons with 20/20 vision farther away than 210 ft could not read the placards. Some fatalities occurred 350 and 450 ft distant. A warning system should have a range equal to the range of the threat.

The VW's fuel tank is located in the front and probably caused the fire.

NTSB-HAR-73-3
Propane Tractor-Trailer Overturn and Fire, US Rte 501, Lynchburg, Virginia, March 9, 1972

At 2:30 PM on March 9, 1972, a tanker carrying liquid propane was traveling north on US Rte 501 at 25 mph. At a point 7.1 mi north of Lynchburg, Va the truck while changing lanes in a 48^{o} curve to the left overturned onto the right shoulder of the road.

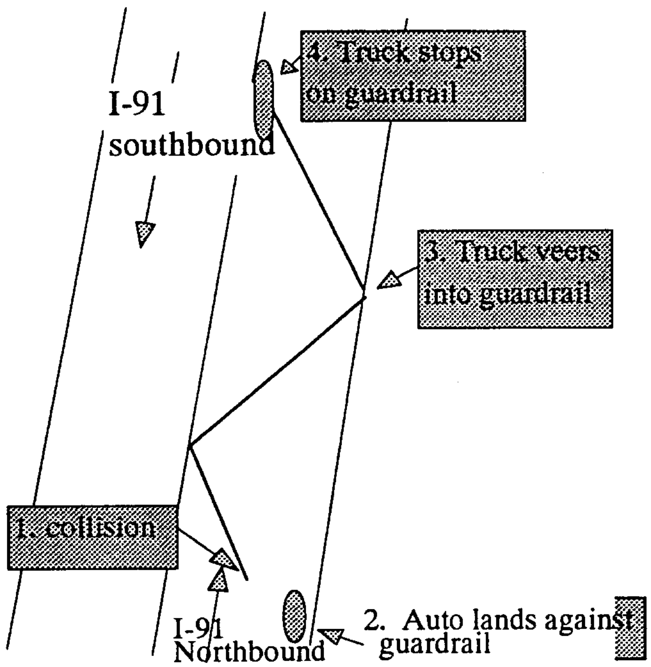
The truck slid along the shoulder on the right side and struck a rock outcropping which ruptured the tank. The vapor cloud spread rapidly and ignited 1 or 2 minutes later.

The truckdriver fled on foot north down a hill but was overtaken by the cloud about 270 ft from the accident when it ignited and he burned to death. Two motorists who stopped north of the truck were severely burned. Occupants of a house located in a hollow below the road and 450 ft from the accident heard the crash, ran from the house and also were severely burned, one dying later. The house, outbuildings and about 12 acres of woodland were destroyed. The trailer contained 9,308 gallons of LPG. The accident occurred on a hilly grade. High CG and surge of liquid contents contributed to overturn. Since LPG is heavier than air, it will move downwards.

NUREG/CR-5892
RW Carlson and LE Fischer, ***A Highway Accident Involving Unirradiated Nuclear Fuel in Springfield, Massachusetts, on December 16, 1991,*** **Lawrence Livermore National Laboratory for the Nuclear Regulatory Commission, June 1992**

At 3:15 AM on Dec 16, 1991 a tractor-trailer carrying 24 unirradiated nuclear fuel assemblies collided with a car traveling the wrong direction on I-91 in downtown Springfield, Mass. The truck was traveling near the legal speed limit of 55 mph.

The truck veered to the left to avoid the oncoming car, who struck the right side of the truck near the fuel tank. The truck continued northbound, striking the center guardrail and outer concrete barrier before coming to rest at the center guardrail. The front axle of the truck separated from the truck during the impact with the concrete roadside barrier, but the fuel assemblies remained in place during the collision. Following the collision, a fire started in the engine compartment which engulfed the tractor and then the trailer. No attempt was made to extinguish the fire which burned for 3 hours.



The fire completely destroyed the tractor trailer and caused significant damage to several containers and their contents. During the fire, eight containers fell off the trailer from a height of about 7 ft and sustained minor damage during the impact. The fire consumed the wood outer containers and caused damage to the inner metal containers. Localized regions near the tires reached temperatures of 1800 ^{O}F. Most of the containers endured flame temperatures of 1300 ^{O}F or less. The plastic fuel rod separators and foam protection for the fuel assemblies burned during the fire. Some of the clad tubes had swollen due to the increased in pressure within the fuel rod, estimated to be 1500 ^{O}F.

No release of radioactive material from the containers. Only minor injuries in the accident.

The truck was traveling from the GE fabrication plant in Wilmington, North Carolina to Vernon, Vermont, a trip normally requiring 24 hours. Two drivers alternate sleeping and driving. Less than one hour of travel remained when the accident occurred.

The truck carries saddle tanks on each side of the cab. Each tank holds 125 gallons. The total inventory on the truck was estimated at 210 gallons.

The containers were secured to the trailer with nylon tiedown straps over a tarpaulin.

Weather conditions were ideal. High scattered clouds and excellent visibility.

The accident site was an elevated interstate with limited access in downtown Springfield. The road is divided. The outer barrier is 3 ft steel reinforced concrete. The inner barrier is a steel beam. The highway is 3 lanes wide with a shoulder. The road is crowned with the high point in the center.

The tractor weighed 8.4 tons; trailer 7 tons; payload 15.8 tons. Placards are not required.

Apparently the driver of the car was intoxicated and entered the highway from the exit, going the wrong direction. Police notification took place 3 minutes after the accident, at 3:18 AM.

The collision was a glancing blow, not head-on and may have caused loss of the truck's air brakes. The truck first veered left and struck the inner guardrail then veered right and more severely struck the outer guard rail. This impact separated the front axle, hood and fenders from the truck. One of the fuel tanks ruptured. The truck came to rest against the inner guard rail. Fire was observed in the cab and the rear trailer tires. The fire burned vigorously for 3/4 hour. About 1 hr after the impact, the tarp, wooden containers and bed of the trailer began to burn. This burned for an additional 2 hours.

No measurable amounts of radioactivity were detected. The inner containers were not opened at the accident scene. New wooden containers were provided by GE. On Dec 18, the fuel assemblies were shipped back to GE.

The containers involved in the accident are Model Nos. RA-2 and RA-3. These are Fissile Class 1, Type A. The container plus assembly weigh 2715 lb; each fuel assembly weighs 610 lb. Each container holds 2 fuel assemblies. The RA series consists of a right rectangular metal inner container cushioned in a wooden outer container, constructed of 1/2 inch plywood. 2 x 4 frame each panel. A 3 in plastic coated honeycomb cushioning material surround the inner metal container.

The fuel assemblies were GE BWR assemblies, with average enrichment 3.11% U-235.

The 20 x 30 foot tarps were constructed of rubber coated canvas. The tie downs were nylon straps, 4in to 6 in wide, with a minimum breaking strength of 13,000 lb. The nylon straps melted early in the fire. The load shifted as components of the truck burned. Four containers remained on the trailer and 8 fell onto the roadway. All containers probably impacted on their lid. Some containers were twisted and had opened. The fuel assemblies could be seen. There was little impact damage to the fuel assemblies.

All wooden components were consumed by the fire. The fuel assemblies appear to have become distorted to match the twisted shape of the metal containers. The cladding was blackened with burnt plastic residue attached. In some cases, the cladding expanded so much that adjacent fuel rods were touching.

The fire department estimated the temperature to be about 1500 ^{O}F, but the fact that one of the leaf springs at the rear of the trailer had annealed to the point its curvature was reversed suggests a flame T closer to 2000 ^{O}F.

Table. Ignition Temperatures and Flame Temperatures for Flammable Materials in Tractor-Trailers and Containers

Material	Ignition Temperature °F	Flame Temperature °F
Wood	>600	1290 to 1475
Plywood	730	1290 to 1475
Paper	500	
Plastic	1160	1290 to 1475
Ethafoam	730	
Rubber	>500	1740 to 1830
Nylon	850	
Epoxy Paint	400 to 480	
Diesel Fuel	490 to 545	1740 to 1830
Asphalt	900	1560 to 1650

The inner containers reached the temperature of the flames well before the end of the fire.

Some of the cladding had a whitish color indicating that the zirconium cladding had oxidized. As the temperature exceeded 1500 °F, plastic deformation occurs. Above 1800 °F, oxidation will occur.

Emergency Response to a Highway Accident in Springfield, Massachusetts on December 16, 1991, Nuclear Regulatory Commission, NUREG-1458, June 1992

The accident occurred at 3:15 AM. The Massachusetts State Police (MSP) are informed of the accident at 3:18, and arrive at the scene at 3:24 AM. Ambulance and fire dept assistance are requested. The MSP identified the contents by the shipping papers, since there were no placards. Two ambulances reached the scene at 3:32 AM. The truck crew was helped into the ambulance and left the scene at 3:56 AM. The 2nd ambulance containing the driver of the car arrived at 4 AM. All 3 were taken to a decontamination room and checked for radiation. The fire dept arrived at 3:25 AM. The MSP advised the fire dept that the truck was carrying a radioactive material, uranium dioxide. The fire dept declared a Level 1 Hazardous Material Incident. This is an incident with which the local personnel can easily handle with initial emergency response crews. Evacuation is not necessary under Level 1. The fire dept reviewed the shipping papers at 3:35 AM and decided to let the fire burn while it obtained more information. A command post was set up at 3:50 AM at a nearby motel.

The fire dept called GE between 3:53 and 4:04 and was advised to isolate the area and let the fire burn. GE called back at 4:50 AM and advised the fire dept to put out the fire. VY officials also advised an evacuation zone of 100 yards and informed the fire dept a response team would be sent in an hour. It also recommended letting the fire burn. A level II hazard, allowing responders to call in additional resources, was declared at 4:50 AM.

GE informed the NRC Operations Center of the incident at 4:43 AM. NRC in turn notified DOT National Response Center (5:25 AM) as well as FEMA. The NRC contacted the Springfield Command Post at 5:55 AM and offered assistance, but the fire was almost out at this point. [This is 2hrs, 40 min after the initial accident. This agency is asleep at the switch.] The fire was allowed to burn out while police maintained traffic control. The fire burned out by 6 AM. Cleanup begins at 9:30 with removal of Toyota car. At 11 AM decision made to move the fuel to Westover Air Force Base in Chicopee, from where it will be repackaged and returned to GE, the present owner of the fuel. At 11:15, a GE rep arrives. At 11:30 a team from VY arrives for cleanup. The Marriot Hotel lobby, the initial command center, was mayhem because the media used the phones and requested information while the fire dept was coordinating the accident response. Media later moved to 6th floor of hotel, with viewing opportunities from roof. By 14:30 VY have completed the loading of fuel assemblies onto 3 flatbed trailers. After cleanup of debris, southbound Rte 91 opened at 15:40. Mass DPW clean up and repair guard rail. Two lanes of traffic opened at 16:52. The total incident had a duration of 13 hrs, 37 minutes. The fuel was repackaged and returned to GE Wilmington on two trucks December 18.

At a followup meeting Jan 13, 1992, MSP stated that the accident showed the need for up-to-date reference materials. Because the S Fire Dept did not have the correct information from CHEMTREC, and because VY and GE both initially told the fire dept to let the fire burn, the wrong decision was made. It would have been wiser to put out the fire.

NRC officials when contacted should have known about the hazard of the material and what to do in an emergency. The NRC deferred to the DOT and DOE, and took some time to make the appropriate calls.

Use of the 24-hour emergency response numbers listed on the shipping papers was not effective. Emergency Response Guide 63 in the *Emergency Response Guidebook* lumps all fissile materials into one category. This is not appropriate since irradiated and unirradiated fuel are entirely different hazards. CHEMTREC was not able to provide appropriate emergency response information. The same goes for CAMEO. It is unclear at this time whether the high temperature damaged the nuclear fuel. Some of the cladding was definitely damaged and could not be re-used.

More than most cities, Springfield had an excellent emergency response plan. This was due a leaking propane truck incident in December 1987 and a major chlorine fire in June 1988. But the information needed by local responders by industry and federal agencies was inadequate.

NTSB-HAR-74-4

Hoppy's Oil Service, Inc, Truck Overturn and Fire, State Rte 128, Braintree, Massachusetts, October 18, 1973

At 5:30 AM on October 18, 1973, a tractor-semitrailer carrying gasoline entered the westbound lanes of State Rte 128 in Braintree, MA. The truck was carrying 8,700 gallons of gasoline and had a gross vehicle weight of 77,535 lbs, and was 4,535 lbs overweight. The speed limit was 50 mph.

As the truck approached an overpass which carried Rte 126 over State Rte 37, the truck traversed a depression 20 ft long and 1 to 1 1/2 inches deep. The rear end of the left equalizer beam of the tractor tandem suspension failed and dropped onto the roadway; the left end of the rear tractor tandem axle then pivoted rearward and the driver lost control. The truck veered across the outermost westbound lane and the paved shoulder of the highway and struck the right side guardrail. As the truck slid 121 ft along the guardrail; the semi trailer overturned onto the guardrail and posts. The cargo tank was punctured and some of the gasoline cargo escaped. The truck then slid on its right side back onto the roadway, coming to rest on its right side about 186 ft west of the point of initial contact. Flames engulfed the truck and spread to the surrounding area, generally following the downslope of the roadway and a nearby exit ramp. The truckdriver died.

At the time of the accident, the road surface was dry and the T was 45 ^{o}F. Traffic was light. Fire damage extended 500 ft along the north edge of the roadway.

St Rte 128 is an 8-lane controlled access bypass highway around Boston. Equalizer beam failure.

NTSB-HAR-74-5

Greyhound Bus Collision with Concrete Overpass Support Column on I-880, San Juan Overpass, Sacramento, California, November 3, 1973

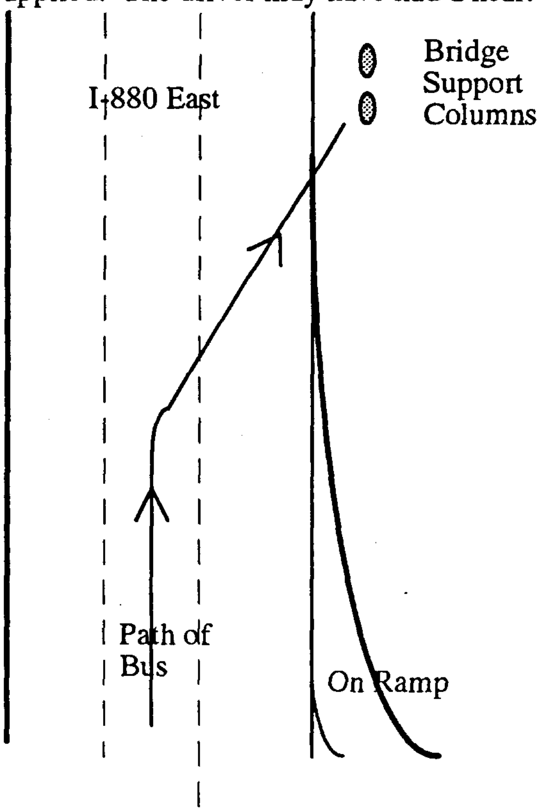
At 9 PM on November 3, 1973, a charter Greyhound bus, eastbound on I-880 near Sacramento, California, ran off the road, overrode a guardrail and collided with a column which supported the San Juan Bridge Overpass. The speed of the bus was about 67 mph. The bus veered from the inside lane to the outside lane.

The 48-inch diameter bridge support column penetrated the center of the bus to a depth of 21 ft. The driver and 12 passengers were killed; 22 passengers were hospitalized for moderate to critical injuries.

The probable cause of the accident was driver incapacitation.

Interstate 880 is a six lane divided highway with 3 lanes in each direction. The lanes are 12 ft wide with a 10ft shoulder. The speed limit is 65 mph. At the time of the accident, the weather was dry and clear.

The basic structure of the bus was light gauge steel and aluminum. The engine and transmission were in the rear. The bus engine was governed so it could not exceed a speed of 67 mph. The overpass column penetrated the center front of the bus to a depth of 21 ft and rove the front axles and wheels back to the cargo dept. The driver's station and controls separated from the bus structure and were thrown against another support column, 52 ft beyond the point of impact. All seats failed. Apparently no brakes were applied. The driver may have had a heart attack because he was clutching his chest when

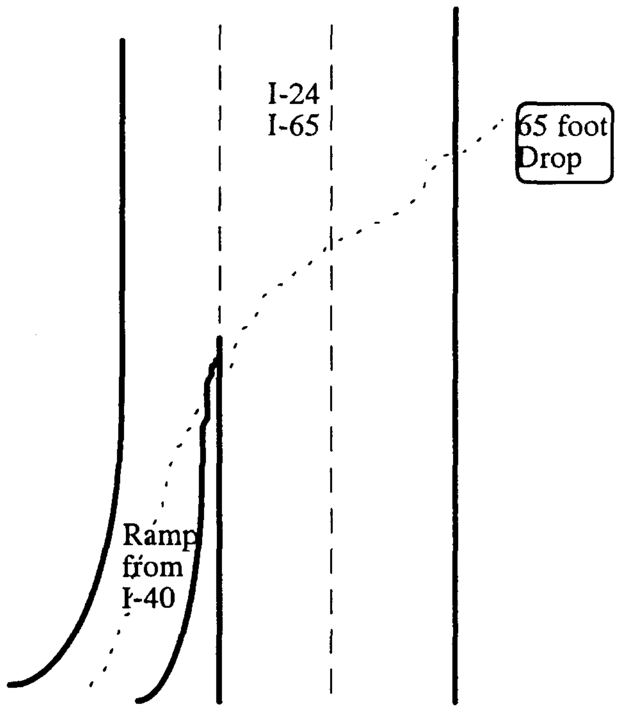


when the accident occurred. The driver was 45 lbs overweight. The passengers who were thrown out of the bus or impacted the column died. The calculated acceleration forces were 7.5g, with an approximate duration of 0.42 seconds, within human tolerance. Decelerated from 65 mph in 21 ft.

NTSB-HAR-74-2
Automobile Crash Off the Silliman Evans Bridge, I-24/65, Nashville, Tennessee, July 27, 1973

About 5:45 AM on July 27, 1973, in a light ground fog, a car crashed through the barrier system on the edge of the Silliman Evans Bridge, I-24/65 in Nashville, TN. Of nine passengers, 7 plus the driver died; none were ejected.

The automobile was traveling on the off-ramp from eastbound I-40 onto northbound I-24/65. When it reached the juncture of the two roadways, the car struck the curb face of a raised concrete island. The driver lost control of the auto which then traveled northeast across two lanes, mounted the curb, overrode the box-beam and plunged through the bridge rail and fell 65 ft to the ground.



The bridge rail consisted of vertical posts 2'11" high and 3 horizontal rails. At the time of the accident, the replacement supports struck by the car were merely resting on the curb without actually being attached to the curb or the bridge structure. The curb, box-beam guardrail and bridge rail were the only components of the bridge damaged. 65 ft of guardrail deflected beyond the alignment of the bridge rail.

The posted speed limit was 55 mph. The auto left the bridge at 30 mph. The ground was littered with highway materials, but it was generally soft.

NTSB-SS-H-2
Collapse of US 35 Highway Bridge, Point Pleasant, West Virginia, December 15, 1967

The US 35 highway bridge connecting Point Pleasant, West Virginia and Kanauga, Ohio collapsed at 5 PM December 15, 1967. 46 persons died in the accident and 9 were injured. There were 37 vehicles on the bridge at the time; 31 of them fell with the bridge and of these, 24 fell into the water and were later recovered. The other 7 vehicles fell with the bridge on the Ohio shore.

The weather at the time was cloudy and the T was 30^{o}F.

The US 35 bridge was an eyebar chain suspension bridge over the Ohio River with a 700 ft center span and two 380 ft side spans. There were two main piers which supported the bridge towers which extend 131 ft above the tops of the piers. The total bridge length was 1753 ft. Water depth was 34 ft.

At about 4:35 PM on December 15, 1967, two witnesses saw objects on the roadway just east of the Ohio tower. Clanging. Two loaded gravel trucks. in the eastbound lane approached the center of the bridge; the vibrations became alarming.

Traffic was stopped in the north or Ohio-bound lane from a point 60 ft east of the traffic light on Ohio Rte 7 at the bridge approach to a point slightly east of the center of the bridge. At 5 PM the bridge collapsed. The Ohio side span fell first, collapsing on the Ohio shore.. The Ohio tower then fell towards W Virginia. The W Virginia tower fell towards W Virginia. The middle portion of the center span turned over towards upstream. Of 64 persons in 31 vehicles that fell with the bridge, 44 died and 2 were missing, presumed dead. of the 39 persons who fell with the center span, only 5 survived. Of 18 survivors, 9 were injured.

By Dec 31, 23 vehicles had been recovered. The roadbed was xxx ft above the water.

NTSB-HAR-71-6
Highway Accident Report, Liquefied Oxygen Rank Truck Explosion Followed By Fires in Brooklyn, New York, May 20, 1970

On May 30, 1970, a tank truck operated by Liquid Carbonic Corp, partially loaded with liquefied oxygen exploded without warning as it was being driven from Victory Memorial Hospital in Brooklyn, New York. The force of the explosion and ensuing fires resulted in fatal injuries to the driver and a bystander, minor injuries to 30 people and substantial property damage.

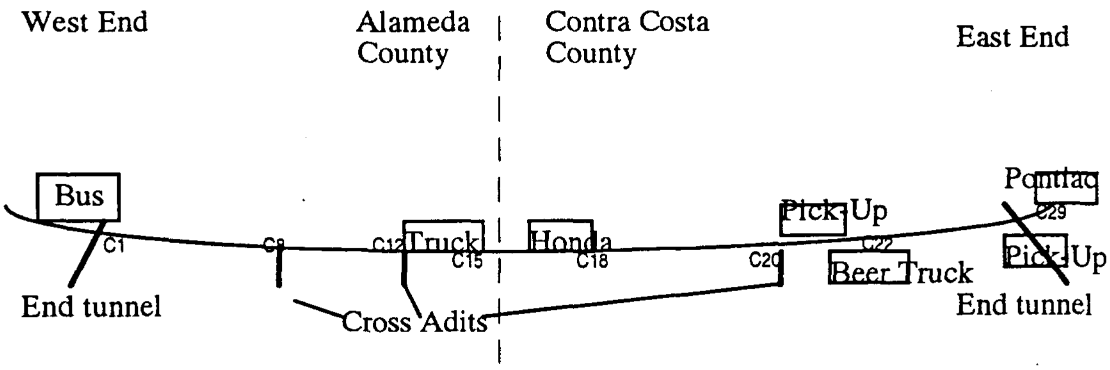
The probable cause of the accident was the abrupt oxidation, without warning of one or more materials inside the cargo tank.

The truck contained 2,550 gallons of LOX, 380 gallons of which were transferred at Victory. Within 50 seconds after competing the transfer, the cargo tank assembly ruptured. The boiling point of LOX is -297.4 ^{O}F. One volume of liquid LOX corresponds to 860 volumes of gas at room T and P. A rupture disk, rated at 249 lb, had burst cleanly. Failure seems to be internally induced due to internal oxidation of impurities. The entire fracture occurred in less than one second.

NTSB/HAR-83/01
Multiple Vehicle Collisions and Fire, Caldecott Tunnel Near Oakland California, April 7, 1982

About 12:12 AM on April 7, 1982, a 1978 Honda Accord westbound on Ste Rte 24 entered the one-way North bore of the Caldecott Tunnel near Oakland, California.

Figure. Plan of California Ste Rte 24 through the Caldecott Tunnel, with final resting position of vehicles. Tunnel is 3371 ft long.



The Honda moved to the left lane of the two-lane roadway, struck the left curb and was redirected into the right lane and then back to the left lane before slowing and coming to a stop adjacent and parallel to the left curb. Two drivers passed the Honda while it was slowing and three others passed it while it was stopped. The Honda's emergency flashers were on.

A 1977 Kenworth tanker towing a 1977 Clough full tank trailer filled with gasoline entered the tunnel shortly after the Honda. The tanker was followed by a 1975 Grumman Flxible passenger bus occupied only by the driver followed by a Ford pickup truck occupied by the driver and passenger. The bus was traveling about 55 mph as it entered the tunnel in the right lane. The bus completed a 2400 ft radius curve and entered a 1740 ft straight section, with a sight distance of 485 ft. The bus was about 150 yards in front of the pick-up truck. The bus' stop lights went on and the bus made a sharp move to the left lane. When the bus moved to the left lane, the pickup driver saw the tail and clearance lights of the tank truck on the right side of the road. The bus struck the left wall of the tunnel, bounced back and the right front of the bus struck the left side of the tank trailer.

The tank truck driver said he was traveling 40 to 45 mph in the right lane when he observed the stopped Honda near the left curb. He saw the bus in the rearview mirror as it was overtaking him. The bus moved to the left to pass the truck and was confronted with the Honda in the right lane. Puffs of smoke from the bus tires as he brakes just before the left front bumper hit the Honda. The bus then had intermittent contact with the Honda as it rotated. The right front of the bus then struck the left side of the tank trailer. The two vehicles separated and the tank truck stops a short distance ahead with the tank trailer on its right side. The bus driver was ejected from the bus during the collision and the empty bus continued west on the left side of the road and increasing speed due to a stuck throttle until it struck a support pier just beyond the west end of the tunnel at about the governing speed of 68 mph.

The pickup truck driver, who stopped his vehicle when he witnessed the collision, noticed a small fire and backed his pickup truck to the nearest emergency phone station. When the passenger went to the phone, the driver walked to the east end to advise approaching traffic they could not pass. A beer truck stopped close behind the Ford pickup. 8 or 9 passenger cars stopped immediately behind the beer truck.

Shortly thereafter, thick black smoke began coming from the tunnel toward the stopped vehicles. The first wave of smoke reached the motorists when they were within 200 to 250 ft from the rear of the beer truck. They rolled up their windows and backed out as quickly as possible. A second wave of smoke, hotter and thicker than the first, overtook the backing drivers. The smoke overtook the Ford pickup truck driver and he was unable to reach his passenger who was on the phone. Another driver backed his Ford pickup truck until it was stopped by a Pontiac. The two occupants of the Pontiac stayed in their car. There were loud explosions, the lights went out and tile started falling from the ceiling of the tunnel. Meanwhile the tan truck driver ran from his truck out of the west end of the tunnel.

At the time of the accident, 5 CalTrans employees were in the control room above the west portal and heard loud backfires until there was final thud that shook the building. They saw the bus strike the road support pier at the west end. The console operator heard a phone buzzer within 1 minute of the bus collision and heard a woman's voice saying "there was a whole bunch of accidents in the tunnel." The phone then went dead. The CHP was contacted at 12:13 AM.

The tunnel crew immediately proceeded to the east (2) and west ends (1 and another man went down the stairway from the console room and observed the tank truck driver running out of the tunnel. He returned to the console room and again called the CHP and requested fire dept assistance.

The tunnel crewman at the west end checked the damaged bus for victims, found none and drove his tow truck to within 150 yards of the tanker and observed a fire filling the tunnel. He also observed burning gasoline flowing westward in the north lane gutter about 10 to 15 ft in front of the tanker. The rear portion of the tanker was in flames. Since no one was in sight, he backed out of the tunnel and called the console operator at 12:16 AM to report a fire. He stayed at the west end until the fire units arrived.

The east end crew drove tow vehicles through bore 1 and arrived at the east portal within 4 minutes, 12:16 AM. Large black clouds of smoke were pouring out of the entrance. They moved some 100 onlookers back 100 yards from the east portal.

Shortly after 12:16 AM, 2 CHP patrolmen, who were several hundred yards from the west portal of bore 3 heard two explosions and proceeded to investigate. They met the tanker driver at the west end, who told them his rig contained 8,800 gallons of gasoline.

Four units of the Oakland Fire Dept arrived at 12:27 AM and established a command post 100 ft from the west portal; one unit moved towards the east end of bore 3. At

12:26 AM, the CHP contacted the Orinda Fire Dept who arrived at the east portal at 12:28 AM. Though advised of 6 to 8 motorists still inside the tunnel, the Orinda FD could not reach the fire because of the heavy smoke.

Both the Oakland and Orinda fire chiefs struck a second alarm. Four additional units from Oakland arrived at 12:33 AM.

At 12:31 AM, a fire officer arrived at the console room to direct the fan ventilation. But the fans were not turned on and the officer left the fans off for fear the smoke would back up towards the east portal.

The front end of the tank truck came to rest in the right lane, 17 ft east of an 18x36 in storm drain inlet. Gasoline leaking from the damaged trailer ignited and flowed westward down the 4% grade along the right lane curb 280 ft past the storm drain.

The Oakland FD determined that the fuel entered the storm drain and flowed 16 ft through a 6 in galvanized steel pipe beneath the roadway surface to a connector box located 35 ft from the front end of the tank truck. About 1 AM, the fir chief ordered the north and south control valves of the tunnel drain closed to contain the fire within a 5000 gallon holding tank between the valves. He also sent a 2-man sweep team with protective equipment into the tunnel to search for possible survivors. Seven bodies were located: the bus driver, the Honda driver, the two occupants of the beer truck, the two occupants of the Pontiac and the Ford pickup passenger who had phoned the control room.

At 1:09 AM, the CalTrans supervisor arrived at the east portal and conducted an assessment of the structural damage. Firefighters were cleared to enter the tunnel. Between 1:30 AM and 2 AM, firefighters laid hoses from the nearest stand pipes in the center bore through the middle and eastern adits and began fighting the fires. At 2:54 AM, the chief reported the fires were under control. An estimated 200 gallons of fuel had leaked out before the valves were shut.

The tank truck came to rest 1732 ft from the east portal, parallel to the right curb. The tow bar was still attached. Almost the entire cargo tank shell material was consumed in the fire except for a 70-inch by 96 inch bottom sheet section from the rear compartment of the tanker and a 40 inch by 21 foot section from the right side of the trailer, the side resting on the ground. The forward end of the 2 14 foot safety cables between the truck and the trailer were still attached to the truck.

The force of the collision of the bus with the structural pier caused a 17 foot rearward displacement of the center front component. The center of the front axle beam was bent about 6 inches rearward. Sheet metal located below the window was pushed 17 feet rearward.

The Honda Accord was found 1196 ft west of the east portal. All combustible and low melting point materials had been consumed by fire. The beer truck was found 754 ft west of the east portal facing west. The 1965 Ford pickup truck was located 807 ft west of the east portal facing west. The 1980 Toyota pickup was found 136 ft west of the east portal. The 1980 Pontiac was standing 118 feet west of the east portal. All these vehicles incurred extensive fire damage.

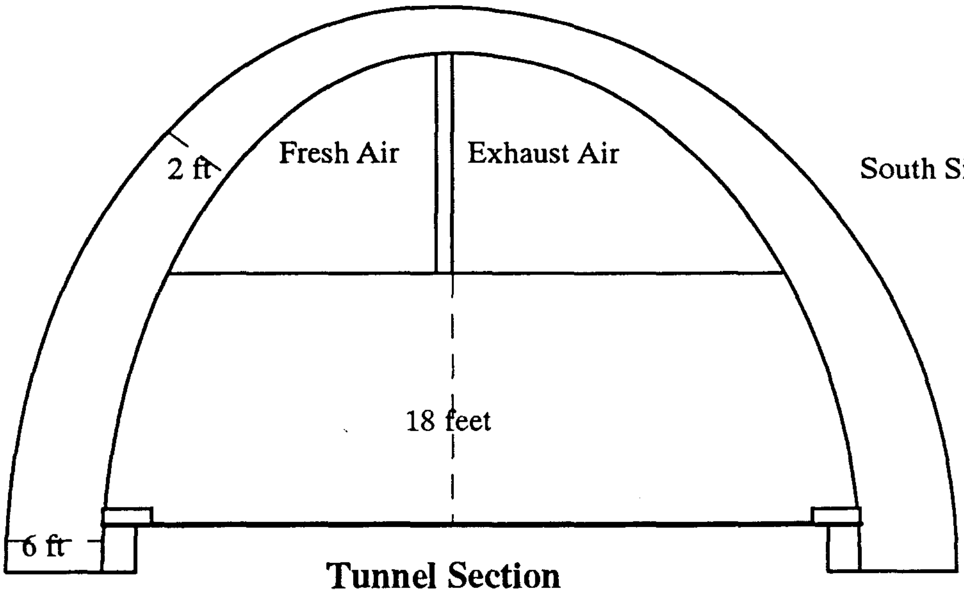
CalTrans engineers determined that the tunnel arch was not seriously affected. In the eastern 1800 ft of the tunnel, tiles, some of the concrete, fluorescent lights, emergency phones, firefighting water supply systems, signs, alarms and the commercial broadcast antenna were destroyed; the concrete ceiling slab was severely spalled above the truck, the steel plates in the ceiling over the exhaust and intake vents were warped and bent, the roadway slab was spalled.

The Honda driver had apparently been drinking. All dead persons, including those in the Pontiac, died of thermal burns and other causes.

Westbound Rte 24 consists of 4 13 ft wide concrete lanes. A maximum speed limit of 55 mph is posted about 6.7 mi east of the tunnel. A 50 mph speed limit is posted about 727 feet east of the tunnel. The tunnel consists of 3 one way, two lane bores and operates with up to four lanes in a direction. At the time of the accident, bore 3 was the only westbound lanes.

The westbound approach to the tunnel is a 4.6 % upgrade. A 4% downgrade begins about 30 feet into the tunnel. The concrete bridge piers, each 2ft by 6 ft, are located 185 ft west of the portal.

The arched walls of the bore are Portland cement covered with 4.25 inch square green tiles. On each side of the tunnel, at the junction of the curved ceiling and the walls is a continuous longitudinal line of fluorescent lights. Fresh air is taken in at the west portal building and carried through a duct above the roadway. The air is discharged through 1ft by 5 ft openings spaced at 15 ft intervals at one side of the ceiling and is drawn out through exhaust portals on the opposite side of the ceiling. For each duct there are two fresh air blowers and two exhaust blowers that have a total capacity of 0.5 million cubic feet per minute.



Tunnel Section

Adits or passageways located on the south wall connect the main bores at 3 locations. The adits have 6' by 2.5' nonlocking, self-closing doors. No signs identify the adits.

On April 28 and 29, 1982, CalTrans conducted traffic volume counts: 63,700 vehicles traveled the westbound route daily; of the 1126 trucks, 26, including 8 flammable materials tankers, carried hazardous materials. 39 accidents occurred over a 3-yr period.

The T was 50° F and wind at 10 knots.

Fire Temperature

CalTrans conducted an analysis of the fire development:

- Examination of copper wires, aluminum castings, plastic light covers and signs, glass, glazed tile and concrete spalling as well as various component metals of the burned vehicles at different heights above the road provide a minimum and maximum temperature determination at various points in the tunnel.
- The upper levels in the tunnel experienced a T of 1914 ± 35 °F near the origin of the fire. The near the roadway was 1650 °F.
- T above 1190 °F at the ceiling extended as far east as station no. 22, where they dropped below 1116 °F to station no. 27 at the east entrance. The heat became more stratified as it moved toward the east entrance. The vehicles further east were exposed to T of 1400 °F to 1600 °F above the vehicle headlight level and red copper oxide on some vehicle wiring indicated T as high as 1900 °F supported by the burning of fuel in these vehicles.
- The air flow into the tunnel at the west end was 15.5 mph, over the hottest portion of the fire between station no. 14 and 18, it was 71 mph with a gradual reduction to about 32 mph at the east entrance.

Rock Slide I-40
News Clips, *The Mountaineer*, Waynesville, N.C., March 1985

About 5 AM, Tuesday, March 5, 1985, a chunk of cliff face broke off the mountain onto I-40, collapsing the westbound tunnel at its front and sending a curtain of rock and debris across the mouth of the eastbound tunnel. The 1,220 ft tunnel is located about 4 mi from the TN/NC line, adjacent to Pigeon River. More than 10,000 cubic yards of rock and earth broke away, an estimated 20,000 tons; one boulder in the west lane was about 75 ft long, 35 ft wide and more than 50 ft tall.

No serious accidents were reported. The weather was rainy and traffic was slower than usual. About 8 trucks got caught in the tunnel. The first truck, carrying chickens, reported seeing no light and slowed down from 45 - 50 mph before striking boulders at the closed end of the tunnel. The location of the tunnel is shown below:

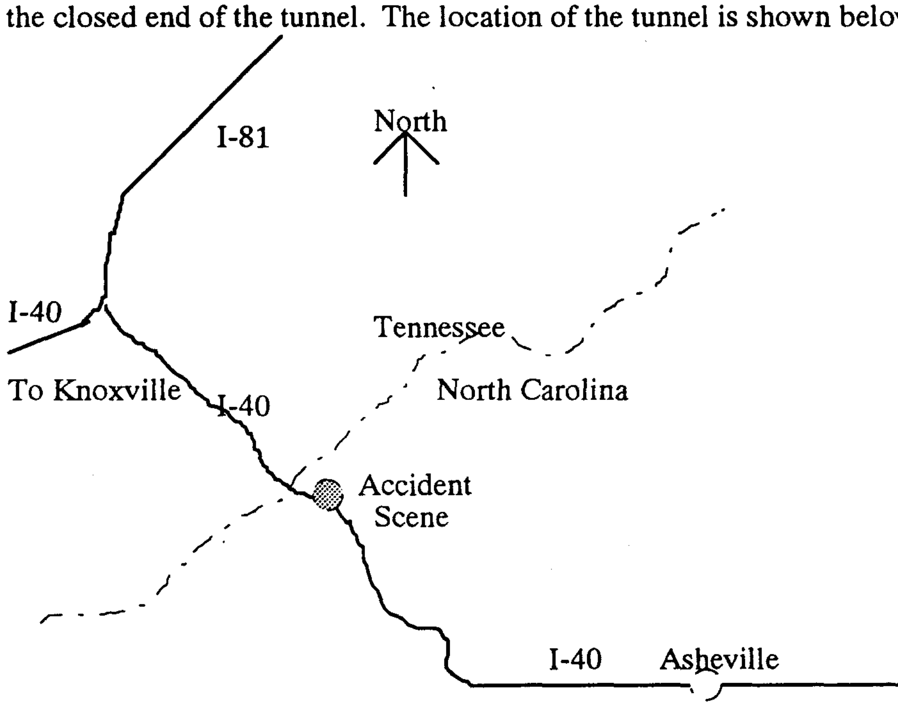


Figure. Rock slide on I-40 closing tunnels 4 mi from Tennessee border.

Others truckers in the tunnel were immediately forewarned of accident by CB radios and jammed brakes, avoiding further accidents. The slide was blamed on the spring thaw and supposedly was due to freeze/thaw cycles and perhaps explosions to make tunnel. Numerous accidents occurred along alternate routes. Traffic was detoured onto 2-lane mountain roads. One tractor trailer plunged several hundred feet down a mountain near Hot Springs when its wheel dropped off the highway shoulder.

This type of accident cannot be predicted. Almost 12,000 vehicles traveled I-40 daily. The road was opened October 24, 1968. In 1984, at least 255 nuclear waste trucks traveled I-40, but this figure refers only to low-level waste shipments, not the considerable number of trucks between the Savannah River Plant and Oak Ridge.

Federal Railway Administration, Factual Railroad Accident Report, Accident Investigation No. A-18-73, Southern Pacific Transportation Company, April 28, 1973.

Accident occurred 8 AM, April 28, 1973, involved explosion of 18 boxcars, each containing 44 tons of 250-lb bombs (336 in each car) being shipped by the Navy from Hawthorne, NV to the Concord, CA. The explosion occurred on the part of the railroad extending westward from Sparks, NV to Sacramento, CA, lying within the city limits of Roseville, CA, in Placer County. The bombs were manufactured and loaded in Hawthorne, NV. The crew departed Thorne, NV at 4:10 PM. The air brakes were applied and released during a brake test, and functioned properly during the trip to Sparks, 128.2 mi westward. The train, Extra 3369 arrived at Sparks 10:30 PM on April 26.

Extra 9117 West left Ogden, Utah at 10:05 AM on April 27 with 104 cars and a caboose and arrived at Sparks about 10:10 PM on April 27. 29 cars were removed from the rear of the train, added a 4-unit helper locomotive and 35 cars, including the 21 cars of bombs to the head end of the train. The train departed Sparks at 11:45 PM on April 27. After Sparks westward trains ascend a mountainous grade to the summit of the Sierra Nevada range. The grade then descends towards Roseville. Electrical arcing on the dynamic brake grids of the first helper locomotive. The unit was taken off line. The train continued westward at 30 mph. In the vicinity of Cisco, 65.7 mi west of Sparks, emergency brake applications stopped the train 3 times. A bent uncoupling lever discovered on the 28th car, removed and wired to the side of the car.

As Extra 9117 descended the mountain grade, the lead engineer used the train air brakes in addition to the dynamic brakes. 55 mi east of Antelope Yard a witness on the south ide of the track saw a brake shoe dragging against the leading wheel of one DODX box car causing the rim of the wheel to glow red and sparks to shower around the wheel.

Extra 9117 arrived at Rosevill at 6:05 AM, moved past the departure yard and entered the east end of track no. 7 in the receiving yard and stopped. Herders moved the first 19 cars of the train, including 3 DODX cars of bombs to the west end of track no. 3, leaving 18 DODX cars of bombs on the west end of track no. 7.

Starting about 8 AM, a series of explosions took place in the bombs loaded in the 18 DODX box cars. The bulk of the bombs exploded during the first 2 hours with sporadic explosions following. The last explosion occurred 4 PM on the following day. Several train employees saw no smoke preceding the explosion. About 5 minutes before the explosion, an engineer saw a pillar of smoke which continued for 2 or 3 minutes before he saw flame. Another 2 or 3 minutes later, a large explosion took place.

The explosive in each bomb is a composition of 80% TNT and 20% grained aluminum called Tritonal. The ingredients are melted together and mixed in a large steam-heated vessel at $T > 80\ ^{o}C$ and poured into the bomb casings. The explosive T for tritonal is $470\ ^{o}C$.

At about the same time, a car inspector heard a sound like a mortar round. He ran 500 ft west, climbed the ladder of a box car on track no. 4 and saw the roof torn open on a DODX car on track no. 7. Fire and smoke were emanating. The carman climbed down and ran in a northeasterly direction. While running another explosion knocked him to the ground. He ran behind a relay case for protection. Another explosion knocked him unconscious and an employee found him lying 200 ft north of the relay tower.

The California Office of Emergency Services set up a command post at 8:30 AM. The American Red Cross and Salvataion Army set up stations to aid evacuees.

The explosions scattered fire and unexploded bombs over a large area. The explosions destroyed 500 feet of double mainline track and 15 yard tracks; obliterated 33 railroad cars beyond recognition; destroyed 128 cars and damaged 76 others. A cricular area with a radius of 6800 feet was totally levelled. Minor structural damage occurred to buildings 2 miles from the blast point while some damage occurred as far as 3 mi away. In all, more than 5,500 buildings were damaged.

The following craters were formed:

- a circular shaped crater 18 ft deep, 50 ft wide
- 75 ft east: a crater 15 ft deep, 50 ft wide at the top and 15-25 ft wide at the bottom
- 30 ft east: a circular shaped crater filled with water 20-25 ft wide
- 40 ft east: a crater 15 ft deep, 100 ft long and 65 ft wide at the top, 85 ft long and 40 ft wide at the bottom
- 60 ft east: a circular shaped crater 15 ft deep, 60 ft wide at the top and 40 ft wide at the bottom
- 50 ft east:, a crater 12 ft deep, 80 ft long and 40 ft wide at the top and 15-20 ft wide at the bottom
- east and alsmost adjacent: one circular in shape, 12 ft deep, 35 ft wide at the top and 20 ft wide at the bottom.

The explosions killed no one, but 13 RR employees injured and 185 non-employees.